Phytoremediation Potential of Plants Growing in a Mined-out Area at Afiesa in the Eastern Region of Ghana

*Okoh P.A. & Zakpaa H.D.

Department of Biochemistry & Biotechnology, Kwame Nkrumah University of Science & Technology, Kumasi, Ghana
*Corresponding author: paokoh@st.knust.edu.gh

Received: 20/03/2025 **Revised: 06/05/2025** **Accepted: 27/05/2025**

Phytoremediation provides a cost-effective means of removing/reducing heavy metal contamination in the soil using plants. This study investigated the phytoremediation capabilities of 11 plant species growing in a mined-out area at Afiesa, a neighbouring town of Kyebi Apapam, in the Eastern Region of Ghana. Plant species and soil samples (composite and reference) were collected and analysed for total arsenic (As), copper (Cu) and lead (Pb) content. The outcome of the study showed different accumulating potentials of various plant species for different metals/metalloids. Three plant species (*P. calomelanos*, *S. jamaicensis* and *T. orientale*) with a BAF > 1, showed bioaccumulation potential for As and hence can be used for phytoextraction of As. Also, *A. cordifolia* showed a whole plant bioaccumulation for Cu >1 and hence can be used for phytoextraction of Cu. Among the plant species investigated, *B. textilis* (1159.5 mg/kg), *P. calomelanos* (2167.5 mg/kg), *S. torvum* (1923.5 mg/kg), *S. jamaicensis* (1350 mg/kg) and *T. orientale* (1669.5 mg/kg) demonstrated hyperaccumulation for Pb. Some of the analyzed plant species demonstrated selective upward transfer (translocation factor) of heavy metals showing their varied capabilities in translocating the absorbed heavy metal to aerial part of the plant (phytotranslocators). It can be concluded that *B. textilis*, *P. calomelanos*, *Solanum torvum*, *Stachytarpheta jamaicensis* and *Trema orientale* are potential phytoaccumulatos of Pb whereas *P. calomelanos*, *S. jamaicensis* and *T. orientale* can be used for phytoextraction of As. Due to the limitation of the current study, it is recommended that a potted study can be carried out to test the phytoextraction dynamics with respect to time. Also, genome analysis can be carried-out on the plants to identify metal-extracting genes.

Keywords; Phytoremediation, mined soil, bioconcentration factor (BCF), heavy metal and metalloids, bioaccumulation factor (BAF), indigenous plants, translocation factor (TF)

Introduction

Gold exploitation contributes immensely to the economies of many developing countries all over the world. In Ghana, revenues from the gold mining industry contribute about 48% of the total revenue generated in the country annually (Danquah, 2019). However, the economic gains obtained from mining activities have been offset by considerable pollution of the environment by mine waste, such as tailings containing high levels of heavy metals. Subsequently, heavy metal pollution with its negative effects on humans and other living organisms has become a matter of concern (Petelka *et al.*, 2019), which needs to be addressed. Various internal processes are altered when plants and animals absorb heavy metals into their systems. Though a few of the heavy metals and metalloids such as copper, manganese, cobalt, zinc and chromium are vital to plants, they are only required in low concentrations for plant metabolism. Heavy metals, taken up by plants, may enter the food chain, becoming available to both animals and humans and subsequently affecting the health of people who consume food crops grown on such contaminated soils (Rehman *et al*., 2017). It has been reported that about one-half of the lead (Pb) intake into the human body occurs through food, and about half of this quantity is from plants (Nagajyoti *et al.*, 2010).

Additionally, mined areas are associated with high environmental effects such as reduced biodiversity, a decline in soil fertility, and degradation of agricultural lands. Following the increasing environmental problems associated with mining, the need for the remediation of degraded land has become an important aspect of mining (Yan *et al*.,2020). In Ghana, the long history of gold mining activities has left many areas heavily contaminated with heavy metals with the unremedied mined soils serving as heavy metal supply points as well a potential sources of special metal accumulating plants (Petelka *et al*., 2019). Chemical and physical techniques such as excavation and chemical treatment of contaminated soil away from the location have been used to remediate contaminated soil, however, these techniques are usually costly and also affect the integrity of the soil to support plant growth (Petelka *et al*., 2019; Mansoor Ali *et al*., 2018).

On the contrary, phytoremediation, a cost-effective means of removing or reducing heavy metal pollution in the environment using plants, provides a better option with the added advantage of being friendly to the environment (Ali *et al*., 2013). Among the various phytoremediation techniques such as phytoextraction, phytofiltration, phytovolatilization, phytostabilization and phytodegradation (Sharma *et al*., 2023), phytoextraction which uses hyperaccumulators, has been widely used due to its competence in cleaning heavy metal contamination. Examples of these hyperaccumulators include *Calendula officinalis*, *Alyssum bertolonii*, *Tagetes erecta* and *Thlaspi caenilescens* which are known to have greater capability to accumulate heavy metals (Glick, 2012). This capability depends largely on the quantities of contaminants the soil contains, the physiological characteristics of plants, and their selective ability for heavy metals (Dominguez *et al.*, 2012; Kashin, 2014; Tapia *et al.*, 2020). A few of the plants identified in Ghana for their phytoextracting capabilities include; *Dalbergia saxatilis*, a medicinal shrub belonging to the family fabaceae and which grows in sandy soils (Hassan *et al*., 2016), has been indicated for removal of heavy metals in a study by Armah *et al*. (2023) where it absorbed 2437±0.003, 33.839±0.002 and 5.855±0.006 mg/kg of Cr, Mg and Pb respectively. Also, *Alchornea cordifolia*, a small medicinal evergreen tree or shrub which belongs to the family Euphorbiaceae (Mokea-Niaty *et al.*, 2018) and known as Christmas bush or Ogyama in Ghana has also been shown by Armah *et al.* (2023) to accumulate various metals such as Mg, Pb, Ni and Cr with concentrations of 282.798±0.004, 26.410±0.002, 4.340±0.005 and 3.414±0.004 mg/kg respectively. *Alstonia boonei* known in Ghana as 'Onyame dua' accumulated up to 2.89±0.004, 20.583±0.003 and 20.049±0.002 mg/kg of Cr, Mg and Pb respectively (Armah *et al.*, 2023). Additionally, *Quassia amara*, a shrub belonging to the family Simaroubaceae and known as bitterwood, with anti-diabetic, antimalaria and also for treating hepatic disorders (Balkristina *et al.*, 2022), has been indicated by Armah *et al*. (2023) to absorb As, Cr, Pb and Mg to concentrations(mg/kg) of 1.092±0.005, 2.507±0.001, 13.026±0.003 and 28.219±0.001 respectively. Another study carried by Bansa and Addo, (2016) to analyse the phytoremediation potential of plants grown on reclaimed spoil soil, identified plant species such as *Xylopia aethiopica*, *Terminalia superba*, *Colocasia esculenta* and *Theobroma cacao* with the ability to amassed various concentration of heavy metals. For a plant species to be selected for phytoextraction, it should accumulate heavy metals in above ground parts, tolerate the absorbed heavy metals and also produce enough biomass (Vangronsveld *et al*., 2009; Suman *et al*., 2018). The capability of plant species to amass heavy metals and metalloids is evaluated using bioaccumulation factor (BAF), determined as a ratio of metal content in plant shoot to soil (Wang *et al.*, 2009; Petelka *et al.*, 2019), bioconcetration factor (BCF),expressed as a ratio of metal content in root to soil (Fitz and Wenzel, 2002) and translocation factor (TF) estimated as a ratio of shoot metal content to root metal content (Antoniadis *et al*.,2021). Though different plants have different abilities to remediate contaminated soils, it is necessary to use local species during phytoremediation to limit the growth of non-native plants (Kowarik, 2010). Unfortunately, in Ghana, data on these native species is limited (Petelka *et al.*, 2019). As a result, there is a need to explore the phytoremediation capabilities of the plants growing in these mined-out sites to unearth more potential hyperaccumulators. Therefore, this study is aimed at investigating the phytoremediation potential of plants growing in abandoned mined-out soil in Ghana.

Materials and Methods

Location of the study site

Afiesa, a neighbouring town of Kyebi-Apapam, is located in the Abuakwa South Municipal Assembly and lies at a longitude and latitude of 6º09'36.6" N, 0º35'51.0" W. The Municipal Assembly is demarcated by five districts including Abuakwa North, West Akim, New Juaben North, Suhum and Atiwa West ('www.asma.gov.gh'). Afiesa, found in a western semi-equatorial area, has a vegetation of moist semi-deciduous forests with dual rainfall peaks in June and October. It receives 125–175 mm of rainfall on average every year. The region experiences mostly constant temperatures, which vary from 26°C to 30°C in August to March respectively. The percentage of moisture in the air is often high year-round, ranging from 70% to 80% throughout the dry season and from 70% to 85% during the wet season ('www.asma.gov.gh'). This study site was chosen because mining activities are rife in the area. The presence of community mining as well as an illegal small-scale (*galamsey*) which has a high possibility of polluting the soil makes it a suitable area for identifying plants for phytoremediation.

Figure 1: Map of Akyem Abuakwa South Municipal in Ghana

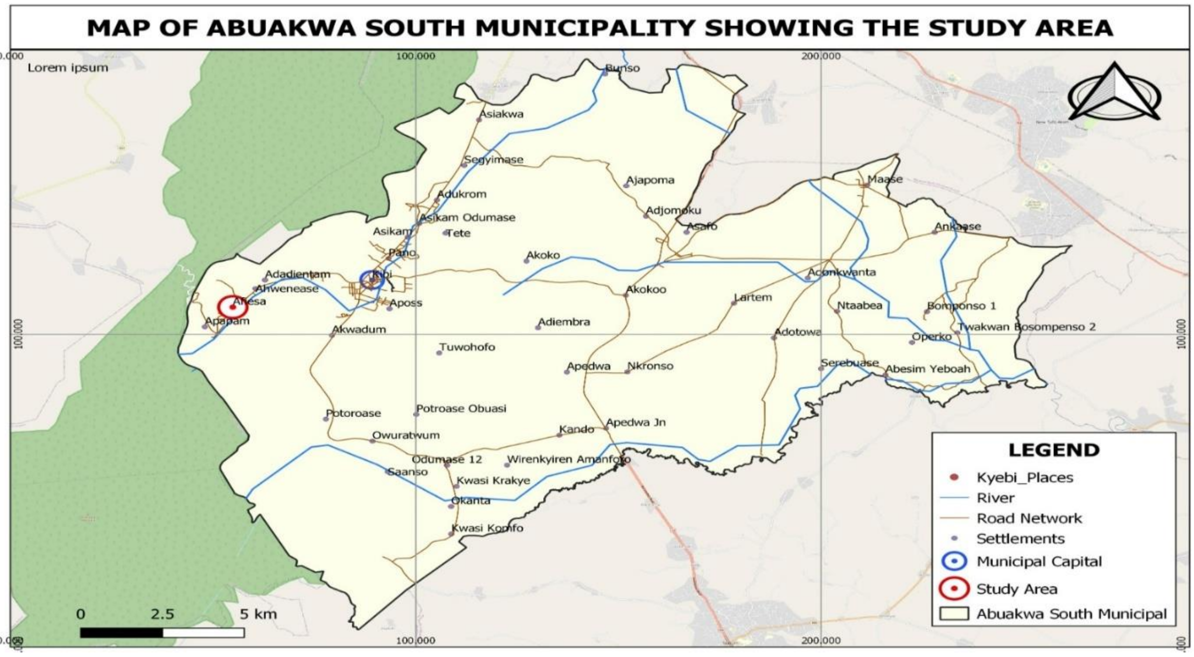

Figure 2: Map of Afiesa in the Municipal Area

Sample collection

The sampling for the experiment was carried out on different points of five plots each covering an area of 25 m^2 within a mined-out area. Plant species *P. calomelanos*, *S. jamaicensis*, *T. orientale*, *B. textilis*, *S. torvum*, *U. lobata*, *S. halepense*, *P. amarylifolius Roxb*, *C. globulosus*, *C. odorata*, *and A. cordifolia* growing in the mined-out soil were harvested randomly from 11 sampling points into polyethylene bags at Afiesa. Whole plants, including the root and shoot, were harvested for shrubs, herbaceous plants and small trees into the polyethylene bags. Soil (tailings) samples within the root region of the harvested plants were also taken within a depth of 15 – 30 cm into polyethylene bags. Similar plant species were composited after identification and soil from their rooting areas also aggregated. Soil samples from an undisturbed/ reference area were also collected (Petelka *et al*., 2019).

Sample preparation

The harvested plant samples were taken out of the polyethylene bags and cleaned first with tap water for 2 minutes and then washed with deionized water to get rid of contaminants or soil bound to the plant surface. Using a stainless-steel knife, the plant roots were cut off from the shoot, and the samples were allowed to air dry on cellophane paper for a week at room temperature. After that, the samples were then oven-dried for 72 hours at 60 º C to achieve a consistent dry weight, and then pulverized using a blender. A 200 mm stainless steel sieve was then used to sieve the ground samples. Mined soil samples were also air-dried for a week and then homogenized using the hands to remove unwanted plant materials present in them. The homogenized soil sample was then oven-dried to a constant of weight 60 º C for 72 hours and 250 g of the oven-dried sample was pulverized using mortar and pestle after which the pulverized sample was sieved using a 2 mm fine mesh to eliminate coarse particles (Nkansah & Belford, 2017).

Soil pH determination

A suspension of soil to water in the ratio 1:2.5 was prepared for the determination of the soil pH as adopted by Nkansah and Belford (2017). The suspension was shaken manually for 60 min at 10-minute intervals to permit the dissolution of soluble salt and subsequent exchange between ions to attain equilibrium before pH was measured using the pH meter (HQ 440d multi-parameter meter).

Soil heavy metal analysis

Soil samples for digestion and subsequent analysis of total Pb, As and Cu were first ashed in an oven at 65 °C for 1½ hours. The dried soil sample was crushed using a mortar and pestle and sieved through a 200 mm metallic mesh sieve. For heavy metal determination, 1 g of the sieved soil sample was weighed into a beaker and 3:1 ratio aqua regia (3 mL of HCl and 1 mL of concentrated HNO_3) was added. The mixture was heated on a hot plate at 100 °C for 10 minutes and then cooled at room temperature. The samples were diluted with 50 ml deionized water, filtered with a Whatman filter paper (Grade No. 41) and then analysed for total Pb, As and Cu using an Agilent 4210 MP AES Spectrophotometer. Blanks were prepared without the sample using the same procedure (Nkansah & Belford, 2017).

Plant heavy metal analysis

Pulverized plant samples were ashed in an oven in different crucibles at 65 °C for 2 hours. A mass of 1 g of each ashed plant sample was weighed separately into a beaker and 3 ml of concentrated HCl followed by 1 ml of concentrated HNO_3 were added. The mixture was heated on a hot plate at 100 °C for 10 minutes and thereafter, left to cool at room temperature. After cooling, the samples were filtered using a Whatman filter paper (Grade No. 41) and then transferred quantitatively into conical tubes where the solutions were topped up with deionized water to the 50 mL mark before the determination of Pb, As and Cu using an Agilent 4210 MP AE Spectrophotometer. Blanks were prepared without the sample using the same procedure (Nkansah & Belford, 2017).

Bioaccumulation factor (BAF)

The plant's capacity to take up heavy metals was found by comparing the heavy metal levels in the plant to that in the soil. The bioaccumulation factor assesses the capability of plants to absorb, transport and amass metals and metalloids in the shoots (Wang *et al*, 2009; Petelka *et al*, 2019).

Bioaccumulation factor (BF) = $[Metal]_{plant} / [Metal]_{soil}$. Thus, plants showing a high BF value (BF>1) are prospective hyperaccumulators and therefore appropriate for phytoextraction (Nazli *et al*., 2020; Pandey *et al*., 2021).

Translocation factor (TF)

The TF estimates the upward movement of elements from the root into above-ground parts. A plant with a TF value of 1 or more, TF ≥ 1, is identified to be good for phytoremediation (Antoniadis *et al*., 2021).

$TF = [Metal]_{shoot} / [Metal]_{root}$. This was determined from the concentration of Pb, As and Cu in the shoot compared to the concentration in the root. Plants with TF>1 are good phytotranslocators /phytostabilizers.s

Results and Discussion

Plant species harvesting

The various plant species harvested from the mined-out site are shown in Table 1. The plant species varied from trees, shrubs, and herbs to grasses.

Table 1: **Plant species harvested on mined-out soil**

Plant Species	Common Name	Plant Family	Growth Form
Alchornea cordifolia	Christmas bush	*Euphorbiaceae*	Tree
Bambusa textilis	Weaver's bamboo	*Poaceae*	Grass
Chromolaena odorata	Acheampong weed/ nature's wound, healer	*Asteraceae*	Herb
Cyperus globulosus	N/A	*Cyperaceae*	Grass
Pandanus amarylifolius Roxb.	Screwpine	*Pandanus*	Herb
Pityrogramma calomelanos	Silver fern	*Pteridaceae*	Herb
Solanum torvum	Turkey berry	*Solanaceae*	Shrub
Sorghum halepense	Johnson grass	*Poaceae*	Grass
Stachytarpheta jamaicensis	Porterweed	*Verbenaceae*	Herb
Trema orientale	Oriental trema/ charcoal tree	*Cannabaceae*	Tree
Urena lobata	Caesar weed/ Congo jute	*Malvaceae*	Shrub

Total heavy metal content in soil

Levels of As, Cu and Pb in both reference and composite mined-out soil samples were measured as shown (Table 2). Total arsenic, copper and lead content in the composite mined-out soil exceeded that of the reference soil. The quantities of heavy metal analysed (As, Cu and Pb) were all higher than the recorded values for the baseline/reference soil (Table 2). Copper (Cu) was found to be the major pollutant among the heavy metals analysed. The Lead content in the mined soil (13.97 mg/kg) exceeded the reference soil levels but was lower than the WHO/FAO (2001) permissible value of 50 mg/kg for soils. The background/baseline value of 11.33 mg/kg indicates a lower level of the metal in the unmined or revegetated soil in the area when compared to the WHO/FAO (2001) recommended value of 50 mg/kg. The observed level of Pb in both reference and mined soils may stem from the fact that, the natural mineral form of lead, lead (II) sulphide (PbS), in the soil is usually obtained in association with gold ore (Petelka *et al*., 2019). The level of lead in the present study was lower than the range of 24 - 39 mg/kg reported by Antwi-Agyei *et al*. (2009). It has been shown that, Lead occurs in higher concentration in the topsoil of most contaminated soil with reduced mobility. However, low pH increases the mobility of the lead in the mined soil (Abubakar, 2015) which is consistent with the result obtained. High lead concentration in soil poses serious health concerns as lead is a poisonous metal even in low concentrations. The copper level obtained was below the WHO/FAO (2001) permissible limits of 100 mg/kg, though higher than reference soil Cu levels (Table 2). Mined gold ores are usually associated with copper as an impurity hence its presence in the mined soils (Fashola *et al*., 2016). High copper content in mined soils have been reported in Ghana by Antwi-Agyei *et al.* (2009) at 39.46 - 71.44 mg/kg and by Bempah *et al*. (2013) at 92.17 mg/kg. The arsenic content recorded for this study (11.84 mg/kg) was lower than the WHO/FAO (2001) recommended limit of 20 mg/kg but higher than the baseline/reference value (Table 2). Arsenic is present in the form of arsenopyrite which is mined along with gold ore. This is then released into the environment when the gold ore is processed for gold (Petelka *et al*., 2019). The arsenic levels obtained in the study were much lower compared to a reported value of 1752 mg/kg by Bempah *et al*. (2013).

Table 2: Content of selected heavy metals in composite mined-out soil and reference sample

Sample	**Heavy metal content in ppm**		
	As	**Cu**	**Pb**
Composite mined-out soil	11.84 ±1.01	36.42 ± 3.24	13.97 ± 1.0
Reference soil	8.39 ± 0.25	11.40 ± 0.99	11.33 ± 1.1
WHO/FAO (2001)	**20**	**100**	**50**

Content of arsenic (As), copper (Cu) and lead (Pb) in plant species.

The levels of arsenic (As), copper (Cu) and lead (Pb) in mg/kg obtained for plant species under investigation are displayed in Table 3. As accumulation in the whole plant exceeded the WHO (1996), standard and varied among the various plant species examined. The highest shoot level of As was found in *Pityrogramma calomelanos* at 24.50 mg/kg and the lowest level was found in *Cyperus globulosus* with a value of 5.00 mg/kg. Additionally, the maximum arsenic quantity was measured in the root of *Cyperus globulosus* with a value of 24.50 mg/kg. For whole plants, the lowest As quantity was recorded in *Chromolaena odorata* and *Sorghum halepense* at 14.50 mg/kg whereas the highest quantity was found in *Pityrogramma calomelanos* (48.50 mg/kg). In comparison, the various plant species accumulated different levels of As in their organs indicating selective absorption in the organs of these plants.

Levels of copper (Cu) in whole plant species were above the WHO (1996), standard levels (10 mg/kg). The maximum amount of Cu in the shoot (17.50 mg/kg) was found in *Stachytarpheta jamaicensis* whilst the least (5.50 mg/kg) was determined in both *Sorghum halepense* and *Trema orientale*. Within the root of *Alchornea cordifolia*, the Cu content was 47.50% higher than *Trema orientale* (6.00 mg/kg) which had the lowest root Cu content. Plant species showed different selectivity for Cu accumulation in both shoot and root organs.

The greatest lead (Pb) quantity, within the whole plant was measured *in Urena lobata* (4003.50 mg/kg) whilst the least was found in *Sorghum halepense* (995.50 mg/kg). However, the level of Pb greatly exceeded the WHO (1996), recommended standard (2 mg/kg). Both shoot and root organs of the plant species recorded Pb amount higher than standard values. In the shoot, the highest Pb content was measured in *Pityrogramma calomelanos* (2167.50 mg/kg) which was more than 52 times greater than *Sorghum halepense* which had the least Pb content (41.50 mg/kg). In the root, however, the highest quantity of Pb was found in *Cyperus globulosus* (2167.50 mg/kg) while the lowest Pb level was recorded for *Trema orientale* (353.50 mg/kg). As observed in arsenic and copper, lead content in both plant parts vary significantly among the plant species. The measured quantities of heavy metals differ for the various plant species analysed. Lăcătuşu *et al*. (2009) opined that plant metal concentrations vary from species to species due to plant reactions to various environmental conditions. This was seen in the results obtained in the study (Table 3). All the plant species under investigation gave arsenic values in the shoot, root and whole plant above the WHO-recommended values in plant tissues (WHO, 1996). Petelka *et al*. (2019) found lower As content (3.78 mg/kg) in the shoot of *C. odorata* while Nkansah and Belford (2017) also reported much lower *C. odorata* As content (1.55 mg/kg, 0.12 mg/kg and 1.67 mg/kg) in the shoot, root and whole plant respectively. Apart from plant species being a key factor in metal absorption, the availability of the metal due to some physicochemical properties of the soil such as pH, soil texture, porosity and soil organic matter (SOM) play an important role. Lead content in all the plant species exceeded the WHO (1996) permissible limit of 2 mg/kg and more importantly the baseline/reference values. The presence of high levels of lead in plant tissues may also be attributed to the soil properties and the plant species involved. According to McGrath and Zhao (2003), hyperaccumulators are plants that accumulate 1000 mg/kg of As, Cu and Pb in their shoot. From the present study, five of the plant species investigated demonstrated hyperaccumulation potential for lead (*B. textilis, P.calomelanos, S. torvum, S. jamaicensis* and *T. orientale*). Copper level in the whole plant exceeded the WHO (1996) recommended value of 10 mg/kg. However, the different levels of copper in both the shoot and root of the plant species indicate the different ability to accumulate copper in their plant tissues. The different levels of the heavy metals (As, Cu and Pb) in plant species analyzed could also be due to the different mechanisms used by plants to detoxify the metal absorbed by the plants. These metals may be complexed to ligands and stored in compartments such as vacuoles (Davi and Bhalerao, 2013). Robinson *et al*. (2003) and Eapen & D'Souza (2005), have both stated that other plant parts such as leaf, trichome and leaf sheath can be used to sequester heavy metals apart from plant vacuoles.

Table 3: Content of arsenic (As), copper (Cu) and lead (Pb) in plants from mined-out site at Afiesa in mg/kg

Plant species	**Heavy metal content in mg/kg (ppm)**								
	As			**Cu**			**Pb**		
	Shoot	Root	Whole plant	Shoot	Root	Whole plant	Shoot	Root	Whole plant
A. cordifolia	10.50± 0.01	10.00± 0.01	20.50 ± 0.01	15.00 ± 0.02	28.50 ± 0.04	43.50 ± 0.12	682.50 ± 0.54	513.00 ±1.10	1195.50 ± 0.60
B. textilis	7.00 ± 0.01	12.00 ± 0.02	19.00 ± 0.01	14.00 ± 0.02	12.50 ± 0.03	26.50 ± 0.11	1159.50 ± 0.33	942.50 ± 0.16	2101.00 ± 1.33
C. odorata	8.00 ± 0.06	6.50 ± 0.03	14.50 ± 0.17	9.00 ± 0.01	9.50 ± 0.09	18.50 ± 0.19	924.00 ±0.44	414.50 ± 0.68	1356.50 ±1.13
C. globulosus	5.00 ± 0.01	24.50 ± 0.02	29.50 ± 0.03	6.50 ± 0.02	13.50 ± 0.04	20.00 ± 0.12	528.00 ± 0.33	2167.50 ± 0.76	2695.50 ±0.98
P. amarylifolius Roxb.	6.00 ± 0.02	12.00 ± 0.01	18.00 ± 0.03	7.50 ± 0.05	8.00 ± 0.02	15.50 ± 0.07	285.00 ± 0.14	1427.50 ± 0.37	1712.50 ± 0.51
P. calomelanos	24.50 ± 0.01	24.00 ± 0.02	48.50 ± 0.03	13.50 ± 0.04	18.50 ± 0.04	32.00 ±0.03	2167.50 ± 0.07	879.00 ± 0.04	3046.50 ± 0.11
S. torvum	11.50 ± 0.05	6.50 ± 0.01	18.00 ± 0.03	14.00 ± 0.06	8.00 ± 0.01	22.00 ± 0.11	1923.50 ± 0.67	943.50 ±1.33	2867.00 ± 1.97
S. halepense	8.00 ± 0.07	6.50 ± 0.03	14.50 ± 0.10	5.50 ± 0.05	8.50 ± 0.13	14.00 ± 0.05	41.50 ± 0.51	954.00 ± 2.34	995.50 ± 2.81
S. jamaicensis	23.50 ±0.00	5.50 ± 0.01	29.00 ± 0.01	17.50 ± 0.02	13.50 ± 0.11	30.00 ±0.03	1350.00 ± 0.33	675.50 ±0.54	2023.50 ± 0.87
T. orientale	12.00 ± 0.02	8.00 ± 0.03	20.00 ± 0.03	5.50 ± 0.01	6.00 ± 0.04	11.50± 0.05	1669.50 ±1.68	353.50 ± 0.18	2023.00 ±1.72
U. lobata	7.00 ± 0.06	16.00 ± 0.01	23.00 ± 0.07	6.50 ± 0.03	28.00 ±007	34.50 ± 0.09	496.50 ± 2.31	3507.00 ±0.75	4003.50 ± 2.98
Standard WHO(1996)		**0.1**			**10**			**2**	

Bioaccumulation (BAF) of As, Cu and Pb in plants compared to soil

Bioaccumulation factor (BAF) for As, Cu and Pb for the various plant species are presented in Table 4. *P. calomelanos, S. jamaicensis and T. orientale* gave BAF > 1 for As with *P. calomelanos* showing the highest BAF of 2.07. Among the plant species analyzed, *B. textilis, C. globulosus, P. amarylifolius Roxb.,* and *P. calomelanos,* indicated As bioconcentration factor (BCF) >1. All the plant species investigated for As, gave a whole plant bioaccumulation factor greater than 1. Except *A. cordifolia*, which gave a whole plant Cu BAF of 1.19, none of the species indicated Cu BAF >1 for the whole plant. Moreover, lead (Pb) BAF > 1 for all the plants evaluated with the highest BAF for Pb (155.15) obtained for *P. calomelanos* and the lowest found in *S. halepense*. The highest Pb BCF and whole plant BAF were found in *U. lobata* (251.04 and 286.58 respectively). The quantities of the heavy metals analyzed in plant tissues had the magnitude, Pb > As > Cu.

All the plant species analysed gave whole plant As bioaccumulation factor (BAF) > 1. Also Shoot BAF for Arsenic was > 1 in *P. calomelanos, S. jamaicensis* and *T. orientale*. This indicates their suitability for phytoextraction for As. However, plant species such as *B. textilis* (1.01), *C. globulosus* (2.07), *P. amarylifolius Roxb* (1.03) and *U. lobata* (1.35) showed a bioconcentration factor (BCF) higher than 1 indicating ability to accumulate heavy metals in the roots of the plants. These may be due to mechanisms that exclude the heavy metal movement to the upper part of the plant but sequester them in plant root cells. *P. calomelanos* yielded a shoot, root and whole plants Arsenic BAF >1. This points to its ability to accumulate As in its roots and subsequently move them to the aerial part of the plants. This is consistent with the observation by Francesconi *et al*. (2002) that *P. calomelanos* is an As hyperaccumulator. Except for *A. cordifolia*, all the other plant species analyzed yielded a whole plant Cu BAF <1 which indicates their inefficiency for copper bioaccumulation. Plant species investigated in this study gave shoot, root and whole plant Pb BAF >1 excluding *S. halepense* with a shoot BAF of 0.43. This shows that *S. halepense* accumulates heavy metals predominantly in its roots due to the plant's ability to form complexes with the metal in the root cells, which are then lodged in root vacuoles (Ali *et al.*, 2013). Plant species showing high root content of heavy metals to shoot content may also employ metal exclusion mechanisms such as the use of barriers in their shoot system which restrict heavy metal movement to the aerial parts (Yan *et al.*, 2020). For lead bioaccumulation, *P. calomelanos* gave the highest lead BAF of 155.15 in this study. Although *P. calomelanos* is a known As hyperaccumulator, it has been shown to accumulate other metals such as lead, cadmium and zinc (Win *et al.*, 2020). A study by Algo *et al.* (2014), indicated that *P. calomelanos* is not a copper hyperaccumulator with a whole plant copper BAF of (0.14 – 0.81) which is similar to findings in this study (whole plant BAF = 0.88). On the other hand, Pulukkunadu and Hedge, (2020) demonstrated that *P. calomelanos* is effective in accumulating both lead and mercury and is therefore good hyperaccumulator of both heavy metals. The different bioaccumulation factor for various metals is an indication of the varied affinity and subsequent absorption of these heavy metals by the plant species under investigation.

Table 4: Bioaccumulation and bioconcentration factors of arsenic (As), copper (Cu) and lead (Pb) in plants

Plant Species	**Bioaccumulation factor (BAF)**								
	As			**Cu**			**Pb**		
	BAF (Shoot)	BCF (Root)	BAF (Whole plant)	BAF (Shoot)	BCF (Root)	BAF (Whole plant)	BAF (Shoot)	BCF (Root)	BAF (Whole plant)
A. cordifolia	0.89	0.84	**1.73**	0.41	0.78	**1.19**	**48.85**	**36.72**	**85.57**
B. textilis	0.59	**1.01**	**1.60**	0.38	0.32	0.72	**82.99**	**67.47**	**150.46**
C. odorata	0.68	0.55	**1.23**	0.25	0.26	0.51	**67.43**	**29.67**	**97.10**
C. globulosus	0.42	**2.07**	**2.49**	0.18	0.37	0.55	**37.79**	**155.14**	**192.94**
P.amarylifolius Roxb	0.51	**1.03**	**1.52**	0.21	0.22	0.43	**20.40**	**102.18**	**122.58**
P. calomelanos	**2.07**	**2.03**	**4.10**	0.37	0.51	0.88	**155.15**	**62.92**	**218.07**
S. torvum	0.97	0.55	**1.52**	0.38	0.22	0.60	**137.68**	**67.54**	**205.22**
S. halepense	0.68	0.55	**1.23**	0.15	0.23	0.38	**2.97**	**68.29**	**71.26**
S. jamaicensis	**1.98**	0.46	**2.44**	0.48	0.36	0.84	**96.63**	**48.21**	**144.84**

T. orientale	**1.01**	0.68	**1.69**	0.15	0.16	0.31	**119.51**	**25.30**	**144.81**
U. lobata	0.59	**1.35**	**1.94**	0.18	0.77	0.95	**35.54**	**251.04**	**286.58**

BAF and **BCF** > 1 are shown in bold

Translocation factors (TF) for As, Cu and Pb contents in plant species

Table 5 shows the comparison of root metal content to shoot metal content (translocation factor). From the TF values obtained, *A. cordifolia*, *C. odorata*, *P. calomelanos*, *S. torvum*, *S. halepense*, *S. jamaicensis* and *T. orientale* indicated that they were good translocators for As. Plants species including *B. textilis*, *S. torvum* and *S. jamaicensis* gave TF > 1 for Cu whilst 7 species (*A. cordifolia*, *B. textilis*, *C. odorata*, *P. calomelanos*, *S. torvum*, *S. jamaicensis*, and *T. orientale*) showed TF values of Pb higher than 1. Among the 11plant species evaluated, *Stachytarpheta jamaicensis* recorded the highest TF for As (4.27), *Solanum torvum* yielded the highest TF value for Cu whereas the largest TF for Pb was obtained in *Trema orientale* (4.72).

The species analysed demonstrated selective movement of metals from the root to the aerial parts of the plant upon uptake from the soil. This shows that the translocation of the various metals depends on the plant species as well as the type of metal involved (Kabata-Pendias, 2000). Plants with TF values greater than 1 are effective translocators (Zacchini *et al*., 2009) and hence good for phytoremediation (Antoniadis *et al*., 2021). In this study, plant species including *A. cordifolia, C. odorata, P. calomelanos, S. torvum, S. halepense, S. jamaicensis* and *T. orientale* gave TF for As greater than 1, implying that they are good translocators and hence suitable for phytostabilization of As. The remaining four species with a TF < 1, may have As restricted to root cells and hence largely excluded from upward movement in the plant. Except for *B. textilis, S. torvum* and *S. jamaicensis*, all other plant species indicated a Cu TF < 1 showing that they cannot be used effectively as phytostabilizers for Cu. *T. orientale* gave the highest TF value of 4.72 among six plant species which were identified to be potential Pb phytostabilizers.

Table 5: Translocation factor of selected heavy metal/metalloid in plant species

	Translocation factors		
Plant Species	**As**	**Cu**	**Pb**
Alchornea cordifolia	**1.05**	0.53	**1.33**
Bambusa textilis	0.58	**1.12**	**1.23**
Chromolaena odorata	**1.23**	0.95	**2.27**
Cyperus globulosus	0.20	0.48	0.24
Pandanus amarylifolius Roxb.	0.50	0.94	0.20
Pityrogramma calomelanos	**1.02**	0.73	**2.47**
Solanum torvum	**1.77**	**1.75**	**2.04**
Sorghum halepense	**1.23**	0.65	0.04
Stachytarpheta jamaicensis	**4.27**	**1.35**	**2.00**
Trema orientale	**1.50**	0.92	**4.72**
Urena lobata	0.44	0.23	0.14

TF > 1 is shown in bold

Conclusion

The results demonstrated the different accumulating potentials of various plant species for different metal/metalloids. Among the plant species investigated, five (*B. textilis, P. calomelanos, S. torvum, S. jamaicensis* and *T. orientale*) showed absolute hyperaccumulation for Pb indicating that they can be employed effectively for the remediation of Pb. Three plant species (*P. calomelanos*, *S. jamaicensis* and *T. orientale*) with a BAF>1, showed bioaccumulation potential for As and hence can be used for phytoextraction of As. From the TF values obtained for the various plant species, it can be agreed that both *S. torvum* and *S. jamaicensis* can be used for phytostabilization of As, Cu and Pb while *A. cordifolia, C. odorator*, *P. calomelanos* and *T. orientale* can be used for both As and Pb phytostabilization. Additionally, seven plant species each can be used for As and Pb phytostabilization while three species can be employed in Cu phytostabilization. Thus, from the study, plant species including *S. jamaicensis*, *P. calomelanos* and *T.*

orientale showed potential hyperaccumulating properties for As while *A. cordifolia*, *C. odorator*, *S. torvum* and *S. halepense* indicated phytostabilizing potential for As. Also, *S. jamaicensis*, *S. torvum* and *B. textilis* are potential Cu phytostabilizers. Apart from *S. halepense* which demonstrated phytostabilizing properties, all the plants investigated showed Pb hyperaccumulating potential. The phytostabilization and accumulating potential of the plants studied revealed that they can selectively be used to remediate heavy metal (As, Cu and Pb) contamination in mined soils. Outcome of the present study implies that the observed plant species possess phytoremediation potential and can be combined for phytoremediation of Pb and As contaminated soils.
It is recommended that a potted study should be carried out to test the phytoextraction dynamics with respect to time. Also, genome analysis can be carried-out on the plants to identify metal-extracting genes. The actual age of mined-out area as well as the various plant species could not be determined to help analyses the rate of heavy metal uptake by plants. Additionally, sample collection was done in the dry season (September) hence certain parameters may be affected when done in the rainy seasons.

Consent to Publish
All authors have given their approval for the article to be published.

Funding
The authors declare that no funds, grant or other support were received during the preparation of this manuscript

Competing interests
The authors have no relevant financial or non-financial interest to disclose''

Authors contributions
The conceptualization and design of the study were done by both authors. Material preparation, data collection and analysis were performed by Patrick Andrews Okoh. The first draft of the manuscript was written by Patrick Andrews Okoh. Review and editing were done by Hilary Domakyaara Zakpaa. All authors read and approved the final manuscript

References
Abubakar, M. (2015). *Heavy metal concentration in cassava cultivated on a re-vegetatively restored mined spoils at an AngloGold concession*, Obuasi-Ghana. Unpublished MPhil Thesis. Environmental Science. University of Cape Coast, Ghana. pp 24 – 25

Adotey, K.J.P, Etornam, A.G, Boahen, Y.O. & Armah, F.A. (2012). A review of the Ethnobotany and Pharmacological importance of *Alstonia boonei* De Wild (Apocynaceae). *International Scholarly Research Network (ISRN) Pharmacology*. Vol. 2012. Id 587160. www.doi.org/10.5402/2012/587160.

Algo, J.L.C, Perez, T. R, Perez, R.E.C. & Claveria, J.R.R. (2014). A survey of indigenous copper metallophytes in the Mankayan Mineral District, Benguet, Philippines, with potential applications to post-mining rehabilitation, in abstracts of papers. *36th NAST Annual Scientific Meeting*, Transactums of the National Academy of Science and Technology, 36(1).

Ali, H, Khan, E. & Sajad, M. A. (2013). Phytoremediation of heavy metals-concepts and applications. *Chemosphere*, 91(7), 869 – 881. https://doi.org/10.1016/j.chemosphere.2013.01.075

Antoniadis, V, Shaheen, S.M, Stärk, H.J, Wennrich, R, Levizou, E, Merbach, I. & Rinklebe, J. (2021). Phytoremediation potential of twelve wild plant species for toxic elements in a contaminated soil. *Environ. Int*. 146. https://doi.org/10.1016/j.envint.2020.106233

Antwi-Agyei, P, Hogarh, J.N. & Foli, G. (2009). Trace elements contamination of soils around gold mine tailings dams at Obuasi, Ghana. *African Journal of Environmental Science and Technology*, 3(11), 353–359. https://doi.org/10.4314 /ajest. v3i11.56263

Armah, F.A, Agorku, E.S, Voegborlo, R.B, Ashong, G.W, Nortey, N.K.E. & Mensah, N.J. (2023). Heavy metal content and health risk assessment of some selected medicinal plants from Obuasi a mining Town in Ghana. *Hindawi Journal of Chemistry*, www.doi.org/10.1155/2023/9928577.

Balkristina, A, Singh, S, Srivastava, D, Mishra, S, Rajput, S.K. & Arya, V. (2022). Quassia amara L.: A comprehensive review of its ethnomedical uses, Phytochemistry, Pharmacology and Toxicity. *The Journal pf Phytopharmacology* 11(3), 194-199. www.doi.org/10.31254/phyto.2022.11310.

Bansah, K. J, & Addo, W. K. (2016). Phytoremediation potential of plants grown on reclaimed spoil lands. *Ghana Mining Journal*, 16(1), 68–75. https://doi.org/10.4314/gm.v16i1.8

Bempah, C. K, Ewusi, A, Obiri-Yeboah, S, Asabere, S. B, Mensah, F, Boateng, J, & Voigt, H.-J. (2013). Distribution of arsenic and heavy metals from mine tailing dams at Obuasi municipality of Ghana. *American Journal of Engineering Research*, 02(05), 61–70.

Danquah, Y.D. (2019). Ghana: Mining of Gold in Ghana. Overview. www.mondaq.com/mining/817190/mining-of-gold-in-ghana-overview. (retrieved on Jan 12, 2022, 11:47 am).

Domínguez, M. T, Aponte, C, Pérez-Ramón, I. M, García, L.V, Villar, R, & Marañón, T. (2012).

Relationships between leaf morphological traits, nutrient concentrations and isotopic signatures for Mediterranean woody plant species and communities. *Plant and Soil*, 357, 407–424. https://doi.org/10.1007/s11104-012-1214-7

Eapen, S, and D'souza, S. (2005). Prospects of genetic engineering of plants for phytoremediation of toxic metals. *Biotechnol. Adv*. 23, 97–114. http://doi.org/10.1016/j.biotechadv.2004.10.001

Fashola, M, Ngole-jeme, V, & Babalola, O. (2016). Heavy metal pollution from gold mines: environmental effects and bacterial strategies for resistance. *International Journal of Environmental Research and Public Health*, 13(12), 1047. https://doi.org/10.3390/ijerph13111047

Francesconi, K, Visoottiviseth, P, Sridokchan, W. & Goessler, W. (2002). Arsenic species in an arsenic hyperaccumulating fern, *Pityrogramma calomelanos*: A potential phytoremediator of arsenic-contaminated soils. *Sci. Total Environ*., 284(1–3), 27–35

Hassan, F.I, Zezi, A.V, Danmalam, U.H, & Yaro, A.H. (2016). Effect of methanol leaf extract of Dalbergia saxatilis Hook.f (Fabaceae) on renal function. *Avicenna J. Phytomed.* 6(6), 592 – 596.
https://doi.org/10.1007/s10661-020-08715-2

Kabata-Pendias, A. (2000). *Trace elements in soils and plants*. CRC Press.

Kashin, V. K. (2014). Accumulation features of microelements in steppe plants of Western Transbaikalia. *Agrokhimiya*, 6, 69–76

Kowarik, I. (2010). Biologische Invasionen: Neophyten und Neozoen in Mitteleuropa. Ulmer.

Kumar, B. M. (2013). Mining waste contaminated lands: an uphill battle for improving crop productivity. *Journal of Degraded and Mining Lands Management*, 1, 43-50

Kumar, P. B. A. N, Dushenkov, V, Motto, H, & Raskin, I. (1995). Phytoextraction: the use of plants to remove heavy metals from soils. *Environmental Science & Technology*, 29(5), 1232–1238. https://doi.org/10.1021/es00005a014.

Lăcătuşu, R, Cîtu, G, Aston, J, Lungu, M. & Lăcătuşu, A. R. (2009). Heavy metals soil pollution state in relation to potential future mining activities in the Roşia Montană area. *Carpathian Journal of Earth and Environmental Sciences*, *4*(2), 39–50.

Mansoor Ali, A.K, Bhat, T. D. & Malik, M.A. (2018). Phytoremediation: A plant-based technology. *Int. J. Curr. Microbiol. App. Sci.*, 7(03), 766-777. https://doi.org/10.20546/ijcmas.2018.703.09

McGrath, S. P, & Zhao, F. J. (2003). Phytoextraction of metals and metalloids from contaminated soils. *Current Opinion in Biotechnology*, 14(3), 277–282. https://doi.org/10.1016/S0958-1669(03)00060-0

Mokea-Niaty, A, Medza-Mve, S.D, Lepengue, A.N, Moupeba, C, Ognalaga, M, Mboumba, P, Toussaint, A. & M'BATCHI, B. (2018). *Alchornea cordifoila*(Schumach&Thonn) Mull.Arg. : A Potential Plant for phytoremediation of Manganese polluted soils. *IJAR*, 6(1), 328 – 337.

Nagajyoti, P. C, Lee, K. D. & Sreekanth, T. V. M. (2010). Heavy metals, occurrence and toxicity for plants: A review. *Environmental Chemistry Letters*, 8(3), 199–216. https://doi.org/10.1007/s10311-010-0297-8

Nazli, F, Jamil, M, Hussain, A. & Hussain, T. (2020). Exopolysaccarides and indole-3-acetic acid producing *Bacillus safensis* strain FN13 potential candidate for phytostabilization

Nkansah, F.K. & Belford, E.J.D. (2017). Heavy metals accumulation by indigenous plants growing in contaminated soil in a gold mining area in Ghana. *J. Nat. Sci. Res*., 7(24) 40 – 41.

Pandey, B, Singh, S, Roy, L. B, Shekhar, S, Singh, R. K, Prasad, B. & Singh, K. K. (2021). Phytostabilization of coal mine overburden waste, exploiting the phytoremedial efficacy of lemongrass under varying level of cow dung manure. *Ecotoxicology and Environmental Safety*, *208*, 111757. https://doi.org/10.1016/j.ecoenv.2020.111757

Petelka, J, A, Bockreis, J.A, Deikumah, J. P. & Zerbe, S. (2019). Soil heavy metal(loid) pollution and phytoremediation potential of native plants on a former gold mine in Ghana. *Water Air Soil Pollut*., 230(11).

Pulukkunadu, T. R. & Hegde, S. (2020): *In vitro* spore germination and phytoremediation of Hg and Pb using gametophytes of *Pityrogramma calomelanos*. *International Journal of Phytoremediation*, https://www.doi.org/10.1080/15226514.2020.1813075

Robinson, B, Green, S, Mills, T, Clothier, B, Van Der Velde, M, Laplane, R, Fung, L, Deurer, M, Hurst, S, Thayalakumaran, T. & van den Dijssel. (2003). Phytoremediation: using plants as biopumps to improve degraded environments. *Australian Journal of Soil Research*, 41(3), 599–611. https://doi.org/10.1071/SR02131

Sharma, J.K, Kumar, N, Singh, N.P & Santal, A.R. (2023). Phytoremediation technologies and their mechanism for removal of heavy metal from contaminated soil: An approach for a sustainable environment. *Front. Plant Sci.*, 14, 1076876. https://doi.org/10.3389/fpls.2023.1076876

Tapia, Y, Loch, B, Castillo, B, Acuña, E, Casanova, M, Salazar, O, Cornejo, P. & Antilén, M. (2020). Accumulation of sulphur in *Atriplex nummularia* cultivated in mine tailings and effect of organic amendments addition. *Water, Air, and Soil Pollution,* 231, 8. https://doi.org/10.1007/s11270-019-4356-x

Wang, S. L, Liao, W. B, Yu, F. Q, Liao, B. & Shu, W. S. (2009). Hyperaccumulation of lead, zinc, and cadmium in plants growing on a lead/zinc outcrop in Yunnan Province, China. *Environmental Geology*, 58(3), 471–476. https://doi.org/10.1007/s00254-008-1519-2

WHO. (1996). Permissible limits of heavy metals in soil and plants. Geneva, Switzerland: World Health Organization.

WHO/FAO. (2001). Codex alimentarius commission. Food additives and contaminants. Joint FAO/WHO Food Standards Programme, *ALINORM 10/12A*. Www.asma.gov.gh (Information retrieved on 15 September 2022).

Yan, A, Wang, Y, Tan, S.N, Mohd Yusof, M.L, Ghosh, S. & Chen, Z. (2020). Phytoremediation: a promising approach for revegetation of heavy metal-polluted land. *Front. Plant Sci.*, 11, 359

Zacchini, M, Pietrini, F, Mugnozza, G. S, Iori, V, Pietrosanti, L. & Massacci, A. (2009). Metal tolerance, accumulation and translocation in poplar and willow clones treated with cadmium in hydroponics. *Water, Air, and Soil Pollution*, 197(1–4), 23–34. https://doi.org/10.1007/s11270-008-9788-7