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Bioaccumulation of Selected Heavy Metals in some Plants Growing Around Artisanal Gold Mining Sites in Kataeregi, Niger State, Nigeria

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ABSTRACT: This investigation was carried out to assess bioaccumulation of selected heavy metals in some plants growing around artisanal gold mining sites in Kataeregi, Niger state, Nigeria and to ascertain the selection criterion for candidate plant's capacity for phytoremediation in the process of cleaning up the metal-contaminated soil of the site. At mining sites, samples of soil and eight distinct plant species were gathered. An atomic absorption spectrometer was employed to ascertain the concentration of bioaccumulation of selected heavy metals in the soil and different parts of the plants. Pb content of the soil was 1071±168.8 mg/kg while Cd, Cr, Zn, and As were 13.38±0.432, 10.26 ±1.635, 194.6±6.245 and As 11.08±2.06 respectively. While the result of hyper bioaccumulation ability of the collected plants shows that *Calotropis procera* recorded highest root and stem Pb contents of 87±31.0 and 87.3±1.20mg/kg respectively. For Cd, *Azadiracta indica*, *E camaldulensis* recorded highest root cadmium content of 1.7±0.28 and 8±0.54 respectively. *Azadiracta indica* recorded the highest Cr in root, stem and shoot measuring 21±6.27, 18±0.38 and 16±0.38mg/kg respectively. *Eucalyptus camaldulensis* and *Vitallaria pardoxa* recorded the highest root, shoot and leaves Zn content of 142±4.8, 107±0.89, 98±0.30,56±0.30, 93±0.86 and 153±0.68 mg/kg respectively. For As, the highest concentration was recorded in root of *Ocimum basilicum* with 11.89±0.01 mg/kg while the stem of *Calotropis procera* recorded highest of 2.70 mg/kg. The three plants examined had bioaccumulation potential and can be used for phytoremediation.

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The Earth's crust naturally contains heavy metals, but because of human activity, their concentration has reached hazardous levels in many ecosystems (Sarma, 2011; Durante-Yanez *et al.*, 2022). The group of elements known as heavy metals, which is composed of fifty-three elements, is identified as pervasive environmental contaminants in industrialized countries and has a density more than 5 g cm^{-3} (Alengebawy *et al.*, 2021). Soil contamination by heavy metals has been in existence for many decades but it has significantly expanded since the last 50 years as a result of technical advancements and growing use of materials containing these metals (Machender *et al.*, 2010; Adewumi *et al.*, 2020; Mohammed *et al.*, 2024b) As ions or in specific compounds, the majority of heavy metals are very hazardous because they dissolve in water and easily enter plant or animal cells through soil absorption (Budi *et al.*, 2024; Sulaiman et al., 2013). The metals typically interact with biomolecules, like proteins and nucleic acids, after absorption, reducing the functionality of those molecules (Adeniji *et al.*, 2023;

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Chandana *et al*., 2024; Mohammed *et al.,* 2024b). Problems with several heavy metals, such as lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As) and mercury (Hg) persist in many global regions (Edo *et al.,* 2024). Particularly, lead (Pb), cadmium (Cd), chromium (Cr), arsenic (As), and mercury (Hg) are thought to be the most hazardous to people and animals (Verma *et al.,* 2023; Mohammed *et al.,* 2024a).

Soil contamination occur by the buildup of heavy metals from mining, heavy metal waste disposal, sewage sludge, paints, manure, pesticides, irrigation of wastewater, animal dung, residues from coal combustion, atmospheric deposition, and chemical spills. Human activity disrupts and speeds up nature's metal geochemical cycle, causing one or more heavy metals to accumulate above normal levels that have been shown to pose a risk to the ecosystem as a whole as well as to human health (Edo *et al.,* 2024). The immediate result of heavy metal bioaccumulation includes loss of grazing, forest, or farmed land as well as the total loss of output, while River siltation and contamination of the air and water are examples of indirect impacts. Eventually, this results in a loss of financial prosperity, biodiversity, and amenities (Numbere *et al.*, 2023).

A plant is considered a hyperaccumulator if the concentration of metals in its shoots is consistently higher than that in its roots. This indicates the plant's unique capacity to take in, transport, and retain metals in their above-ground portions (Deng *et al.,* 2024 and Liu *et al.,* 2024). In a simpler term, hyper accumulators are plants which are often found growing in polluted areas and can naturally accumulate higher quantities of heavy metals in their shoots than roots (Liu *et al.,* 2024).

Considering the extraction of metal from soil can considerably by rational choosing of plant species, understanding of the metal uptake and transport capacities of other plant species or tissues each other, thus providing insight into the selection of suitable vegetation for pollution remediation (Deng *et al.,* 20204; Asiminicesei *et al.,* 2024). Additionally, identifying hyper accumulators is a crucial effort because it holds the key to a successful phytoremediation deployment (Nurrahma *et al.,* 2024).

Researches to identify hyper accumulators in a contaminated site and their subsequent use in site remediation are scarce. This work therefore hopes to identify Lead, Cadmium, Chromium, and Zinc and as hyper-accumulators in the soil of the Kataeregi gold mining site in the Niger State and then test the prospect for certain plants in remediation of polluted soil. Consequently, the objective of this paper is to evaluate the bioaccumulation of selected heavy metals in some plants growing around artisanal gold mining sites in Kataeregi, Niger state Nigeria.

MATERIALS AND METHODS

Plant and Soil Samples Collection: In order to prevent rain from washing away the heavy metals, soil samples were taken prior to the start of the rainy season, as advised by (Kabir *et al.,* 2021). For this, an auger and shovel were utilized. Before a soil sample was collected, the shovel was air-dried and thoroughly washed with distilled water to remove any impurities (*Audu et al.,* 2016; Harrad *et al.,* 2020). Two separate mining locations in the Kataeregi mining area provided ten (10) kg of soil samples, taken in sterile, clean polythene bags at a depth of 0–15 cm. A further 10 kg of soil was collected from the Kataeregi gold processing site. The polythene bags were sealed tightly and sent to the Federal University of Technology Minna's Water Resources, Aquaculture and Fisheries Technology laboratory for analysis. The control soil was obtained at Maiwayo village, a few kilomitere from Kataeregi, where there is no mining activity.Plants that thrive in the vicinity of the gold mining site are tolerant of pollution was identified. For shrubs and other lower plants, the entire plant, including the roots and basal regions, will be collected. From higher plants, leaves, a portion of the stem, and roots were harvested. A voucher label was attached to each item while it was being gathered. Parts that needed to be inspected for identification were stored apart and used the technique of (Leonie and Bronwen, 2011; Rimet *et al.,* 2021). Identification of such plants will be achieved by the aid of herbarium specimens at Federal University of Technology Minna Herbarium.

Initial Plant and Soil Preparation

2 mm for analytical investigations the plant samples were cut into little pieces and meticulously cleaned with ionized water in an effort to eliminate any embedded soil or particle residues. The plant samples were divided into sections of roots, stems, and leaves (Abdullahi *et al.,* 2016; Zhang *et al.,* 2021). The plants were allowed to dry outside in the laboratory on cardboard paper for two weeks, (Audu *et al.,* 2016; Capozzi *et al.,* 2020). The desiccated samples were pounded to fine powder using porcelain and mortar and retained in white nylon.

Analyzing the soil sample's chemical composition: Employing a calibrated pH meter, the soil's pH was ascertained and three replicated determinations were carried out on each sample (Abdullahi *et al.,* 2016; Kicińska *et al*., 2022). By multiplying the proportion of organic carbon content by 1.724 and assuming that organic matter is made up of 58% carbon, the Walkley-Black wet oxidation method was utilized for determining the amount of organic carbon in the soil (Walkley and Black, 1984; Shamrikova *et al.,* 2022). Available P was calculated by applying the conventional Olsen extraction technique (Olsen *et al.,* 1954; Younis *et al.,* 2022). Utilizing an atomic absorption spectrophotometer, the soil's Ca and Mg contents were assessed, and a flame photometer was used to measure the K content (Guangming *et al.,* 2017; Bisergaeva *et al.,* 2020). With distilling ammonium that was replaced by sodium, the 1N ammonium acetate technique was used to estimate the capacity for cation exchange of the soil at a pH level of 7 following displacement. (Nunes and Mulvaney, 2021).

Samples digestion and analysis: 1.0g of the soil sample was weighed into a 100 cm3 beaker, and 10.0 cm3 of 1:1 HNO_3: H_2O was then added. Once the mixture reached room temperature, it was heated to 105°C for an hour on a hot plate. Then, 5.0 cm^3 of concentrated HNO_3 and 1.0 cm^3 of hydrogen were added in turn. 5.0 cm^3 of HCl (hydrochloric acid) and peroxide (H_2O_2). After the mixture was established, it was strained and deionized water to a final volume of 100 cm^3 within a flask with volumetric fill. In accordance with Audu et al. (2016) and Li et al. (2021), the plant samples were broken down. Specifically, 0.50g of the pulverized sample was measured into a 100cm^3 beaker and 5cm^3 of concentrated HNO^3 and 2cm^3 pychloric acid ($HClO_4$) was included. After that, the combination was heated at 95°C on a hot skillet until the digest was transparent. After diluting the digest with ionized water and filtering it into a 100cm^3 conical flask, further ionized water was added to make up the difference. Heavy metals content was analyzed using an Atomic Absorption Spectrophotometer (Buck Scientific AAS, Model 210 VGP). Plotting absorbance data against concentrations allowed for the construction of calibration curves. The metal concentration in sample digests is calculated by interpolation (Audu and Lawal, 2006; Kamalu and Habibu, 2023).

Determination of Contamination factor (C.F) of Heavy Metals in Soil: To determine the contamination factor (CF), the metal concentration level in each sample was divided by the background value (Ustaoğlu and Aydin, 2020; Rahman *et al.,* 2022). The maximum allowable limit set by the WHO (2017) for each metal found in the soil and plants was chosen for this investigation as baseline values for determining the contamination variables in soil, plant, and water samples in that order, respectively.

Accumulation/enrichment coefficient: Enrichment coefficient was identified by (Shirani *et al.* 2021) as the heavy metal element concentration in plant above ground portion multiplied divided by the concentration of heavy metal elements in the soil. The subsequent formula was utilized to assess the enrichment coefficient:

$$EC = \frac{[metal\ in\ shoot]}{[metal\ in\ soil]} \quad (1)$$

Where EC = Enrichment Coefficient

Translocation factor: According to Dinu *et al.* (2020), translocation is defined as the ratio of heavy metals in the plant shoot to those in the plant root. The following equation was used to evaluate it:

$$TF = \frac{[metal\ in\ shoot]}{[metal\ in\ root]} \quad (2)$$

Where TF = Translocation Factor

Absorption/bioaccumulation factor: The bioaccumulation factor, which measures the proportion of heavy metals in roots compared to those in soil, was calculated using the equation that follows (Hu et al. 2020):

$$BF = \frac{[metal\ in\ root]}{[metal\ in\ soil]} \quad (3)$$

Where BF = Bioaccumulation Factor

As contenders for soil phytoremediation, three (3) plant species from Kataeregi were selected based on their higher heavy metal accumulation than the remaining plant species gathered.

RESULTS AND DISCUSSION

Metal Concentration in Kataeregi Soil: Table 1 shows an amount of heavy metals (mg kg-1) in soil that was examined and gathered from gold mining sites at Kataeregi, together with the collected control soil. The polluted soil had higher concentrations of every metal under investigation. With 1071 mg kg-1, lead content is the highest ever reported, followed by Zn, Cr, Cd, and As, at 194.6, 26.2, 13.38, and 11.08 mg kg-1, in that order. The amount of metals in the polluted soil differed significantly ($p<0.05$) from the control soil. Based on the result, the polluted soil had an extremely high Pb concentration, which exceeded the World Health Organizations' regulatory guideline (2017) The study further asserted that Pb has the highest recorded content of 1071 mg kg^{-1}, which is in contrary with the finding of (Yahaya *et al.,* 2021) who stated that, the Pb concentrations in arable soils exceeded the international standard of 300 mg kg-1 in all processing sites. Moreover, exceeded the 85 mg kg-1 maximum permitted limit in Nigerian soils as determined by Nigeria's Department of Petroleum Resources (DPR 2022). Nevertheless, the Pb level found in his research was lower than that of the findings published by Tsuwang *et al.* (2014) from the same soil, where Pb contents of 4152, 3920, 3193, and 2637 mg kg-1 were observed in four (4) of the study's twelve (12) locations. The results also revealed a significant difference in metal concentrations ($P < 0.05$) in metal concentrations between the polluted soil and the control. The Cd concentrations of Kataeregi contaminated site was relatively significantly higher than the 13.38 mg kg-1 maximum permitted content in Nigerian soils as established by the Department of Petroleum Resources of Nigeria (2022). With a concentration of 0.967 mg kg-1, Maiwayo (the control site) has a value below the global Cd threshold (1.4–19.5 mg kg–), as determined by various nations (Abdul *et al.*, 2010). This agrees with the study of (Salisu et al. 2016 of Bagega soils, Islam *et al.*, 2020; Yahaya and Fatima *et al.,* 2021) respectively. The maximum acceptable concentration (MAC) of 6.4 mg kg-1, which is the guideline specified by the Canadian Soil Quality Guidelines (CSQG), is likewise exceeded by the Cr concentrations of 10.26 mg kg-1 at the polluted site in Kataeregi (Moghtaderi *et al.*, 2020) for the protection of the agricultural and human health values for each metal. The Cr concentrations detected in his investigation was lower than those of the values reported by Jamil *et.al.* (2023) from the same soil in which Cr contents of 20.10, 18.43, 27.00 and12.00 mg kg^{-1} in four (4) locations was reported in the study. However, the lower values of Cr concentrations, extremely possible that the pollutants crept into the ground water through the soil (Yusuf *et al.,* 2018). The results also revealed a significant difference in metal concentrations ($P < 0.05$) in metal concentrations between the polluted soil and the control.

The highest authorized concentration of 140 mg kg-1 is the maximum permissible level, and the Zn concentrations found in the Kataeregi polluted site were 194 mg kg-1. Since Maiwayo (the control site) has the lowest concentration, the considerable variances between the locations suggest that mining activities have a significant impact on the variations. The studied is in disagreement with the (Yahaya *et al.,* 2021). The Department of Petroleum Resources of Nigeria has defined maximum allowed concentrations of Ni and Zn in Nigerian soils of 140 mg kg and 35 mg kg-1, respectively, which are fewer than the quantities found in the study sites (WHO 2022).

The Arsenic (As) concentrations recorded in Kataeregi contaminated site was 11.08 mg kg^{-1} Which is relatively or comparatively higher than the Canadian Soil Quality Guidelines' maximum permitted value of 9.8 mg kg-1 (CSQG) (Moghtaderi *et al.*, 2020). The finding was in agreement in three (3) of the four (4) regions, the study by Jamil *et al.* (2023) from comparable soil recorded arsenic contents of 9.92, 11.00, and 12.05 mg kg-1. The study showed that these values were exceeding the limit, harming the soil, crops, and human health.

Table 1: Content of Pb, Cd, Cr, Zn and As in the contaminated and control soils

	(**Each Observation Was Based On Three Replicates**) **Content = Mean ± SE**				
Sample	**Pb (mg/kg)**	**Cd (mg/kg)**	**Cr (mg/kg)**	**Zn (mg/kg)**	**As (mg/kg)**
Contaminated Soil	1071±168.8^{a}	13.38±0.432 ^{a}	10.26±1.635^{a}	194.6±6.245^{a}	11.08±2.06^{a}
Control Soil	1.07±0.4175^{b}	0.986±0.04^{b}	0.1349±0.0882^{b}	14.67±0.4819^{b}	3.43± 1.49^{b}

** Significant differences (p<0.05) are shown by values in the same column with distinct superscripts.* ***Key: CS:*** *Contaminated Soil,* ***CTRS:*** *Control Soil*

Chemical Characteristics of Contaminated Soil: The chemical characteristics of the soils utilized in this investigation were listed in Table 4. The contaminated soil had a higher cation exchange capacity 4.51±0.31 and 4.13±0.12 mg/100 g content respectively, as well as a higher pH value6.7±0.06 and 6.3±0.15, respectively and a higher percentage carbon content 5.57±0.41 readings. In contrast, the contaminated soil had lower available phosphorus, available potassium, magnesium, and calcium contents with content readings of 10±0.52, 134±9.0, 996±29, and 840±583 than the control soil. The cation exchange capacity (CEC) of the polluted soil was 5.41 ± 0.21 meq 100 g-1, greater than that of the control soil, which had a CEC of 4.93 ± 0.12 meq 100 g-1, according to the results of the physical and chemical studies of the contaminated and control soil. This might be the result of soil's increased ability to absorb metals, which raises the capacity for exchanging ions. A high concentration of heavy metals is expected to be accompanied by a high cation exchange capacity (Xiao *et al*., 2017). The result is in contrast to the findings of Salisu *et al.* (2016), who stated a reduction in pH concentration (6.2). The percentage carbon level of 5.57% is considered standard (Suleiman *et al.*, 2019). The contaminated soil had a higher pH value than the control soil (6.7±0.06 and 6.3±0.15, respectively). Additionally, the available P and K were higher in the control soil than in the contaminated soil, indicating that the control soil was richer in compost than the contaminated soil (Hu, 2021). Plant species affect how much a given plant absorbs heavy metals, although soil properties and metal polymorphism also play a role in this process (Parvin *et al.*, 2022). High soil property values, such as a high pH level, are said to reduce metal dispersion in soils and, consequently, plant uptake (Jia *et al.*, 2021).

The research aligns with the findings of Opoku *et al.*, (2020), who reported that the soils in the studied locations had low levels of organic carbon, total nitrogen, and phosphorus, possibly as a result of mining activities. There are reports that mining operations cause vegetation to be removed and subsequently plant nutrients to be lost. The two nutrients that limit the development of plants in soils, particularly those in mined areas, are nitrogen and phosphorus (Opoku *et al.*, 2020). The results of this investigation showed that the total nitrogen levels in the mined regions were extremely low (<0.1%), which may have resulted from the removal of plant cover and related waste products during mining activities. This is a typical characteristic of tropical soils, where N concentrations are typically significantly low—below 0.2% (Liao *et al.,* 2021). According to Liao *et al.* (2021), this finding implies that introducing N-fixing plant species could be a successful strategy for fertilizing damaged mine regions. Despite being present in soils in both organic and inorganic forms, phosphorus is the second primary nutrient that limits plant growth (Jilani *et al.*, 2021). According to the current study, P is highly available in the post-mining area but less so in restored areas where mining is still ongoing. These results are consistent with recent research that found that mine-degraded or stockpiled soils have insufficient amounts of available P (Jilani *et al.*, 2021) (Kumari and Maiti, 2022) state that mine soils gradually increase their fixation of P, which inhibits plant growth and development. The results of this investigation also demonstrate that the amount of accessible P in the soil rose as the restoration period (measured in years) developed.

Table 2: Chemical properties in mg kg^{-1} of soil from kataeregi mining sites

		(Every observation was supported by three Replica) **Content = Mean±SE**					
Sample	**CEC**	**Ph**	**%Carbon**	**Available P**	**Available K**	**Mg**	**Ca**
CS	5.21±0.21^{a}	6.7±0.06^{a}	5.57±0.41^{a}	7.04±0.26^{a}	132.7±7.2^{a}	297±12.27^{a}	168±23.8^{a}
CTRS	5.07±0.12^{b}	6.3±0.15^{b}	0.94±0.022^{b}	12±0.12^{b}	138±9.0^{b}	986±34^{b}	870±385^{b}

** Significant differences (p<0.05) are shown by values in the same column with distinct superscripts.* ***Key: CS:*** *Contaminated Soil,* ***CTRS:*** *Control Soil*

*The Assessment of Native Plants Capacity for Hyper-Accumulation in The Vicinity of Gold Mining Sites in Kataeregi***:** Tables 5 to 9 show the findings derived from the gathered plants' capacity for hyperaccumulation for Pb, Cd, Cr, Zn, and As. Among all the plants gathered, *C. procera* possessed the highest Pb content in its roots, stem, and leaves (87±31.0, 87.3±1.20, and 33±5.40 mg/kg, respectively). For Pb, Pb content accumulation factors greater than 1 were recorded by *C. Procera, E. camaldulensis*, and *Guiera senegalensis*. Additionally, the Pb content that was measured by *A. indica, C. procera, and E. camadulensis* exceeds 10 times the background Pb value in an untainted environment.

Table 3: Lead accumulation (mg kg-1) in selected plant tissues extracted from the Kataergi mining site

	Plant parts		
Plant Species	**Root**	**Stem**	**Leaves**
Azadiracta indica	57±2.30	67.2±33	27±0.43
Calotropis procera	87±31.0	87.3±1.20	33±5.40
Eucalyptus camaldulensis	68±2.60	74±3.40	57±3.80
Guiera senegalensis	2.4±0.13	3.7±0.42	3±0.60
Isoberliniadoka	13±2.40	8.7±0.44	6.5±0.38
Ocimum basilicum	32.1±1.20	43±2.21	4.5±0.50
Piliostigmareticulatum	21±0.14	11±0.28	8.4±0.37
Vitallariaparadoxa	7±0.43	6.7±0.07	4.12±0.40

Concentration of plants from non-mining site:Pb 5mg/kg(WHO,2017)

According to Xiao *et al.* (2017) and Wu *et al.* (2021), the results of a hyper-bioaccumulation study conducted on a subset of metals found in plants near Kataeregi gold mining sites indicate that neither of the examined plants fulfilled the Pb hyper-bioaccumulation Pb threshold, which is 1000 mg kg-1. Additionally, all of the plants had enrichment coefficients for Pb absorption that were less than 1, with the exception of *A. indica, O. basilicum, E. camaldulensis,* and *G. senegalensis*, which had translocation factors greater than 1, indicating that they were strong hyper-accumulators of Pb.

For Pb, the predicted bioaccumulation factor was less than one in every plant under study. Of the 220 plant species examined in a lead and zinc mining region in China, (Hesami & Ghaderian, 2018) found that none exhibited a bioaccumulation factor more than 1. The Pb enrichment coefficient, translocation factor, and bioaccumulation factor in the examined plants were all extremely low, despite the significant levels of Pb contamination in the region.

This might be because of the nature soil's composition, since studies have indicated that the subsurface soil from Kataeregi connected with gold had elevated Pb depositions (Jamilu, 2023). This is one of the limitations of phytoremediation technique, according to the US Environmental Protection Agency (US-EPA), since the roots of the chosen plants might not reach the level of Pb-contaminated soil.

After being absorbed by the roots, Pb has limited dispersion as evidenced by the finding of Pb bioaccumulation in plant tissues, which reveals that roots collect more Pb than shoots and leaves. Some studied species have high concentrations of metals in their roots and low levels of metal translocation to above-ground tissues, indicating that they can absorb and translocate metals in a relatively well-balanced manner even in highly metal-polluted environments (Xiao *et al.,* 2017; Wu *et al.,* 2021). The Pb levels in the shoots of *A. indica, C. procera,* and *E. camaldulensis* are 10 times greater than the background Pb value of plants in the uncontaminated environment, indicating that these plants are good hyper-accumulators of Pb. WHO (2017). (Haghighizadeh *et al.,* 2024). It has been found that *E. camaldeulensis* established in Pb-contaminated soil accumulates more Pb than the same plant species grown on control soils (uncontaminated soil).

In Table 4, *Azadiracta indica* and *E. camaldulensis* had the highest Cd content in their roots (1.7±0.28 and 1.8±0.54 mg/kg, respectively), while *Isoberlinia doka* had the highest Cd content in their leaves (3±0.19 mg/kg). Not a single plant was capable of obtaining Cd content greater than ten times that of plants from non-contaminated environments.

Table 4: Cadmium accumulation (mg kg-1) in selected plant tissues extracted from the Kataergi mining site

	Plant parts		
Plant Species	**Root**	**Shoot**	**Leaves**
Azaddiracta indica	1.7±0.28	1.3±0.43	1.2±0.008
Calotropis procera	0.89±0.11	0.92±0.33	0.9±0.35
Eucalyptus camadulensis	1.8±0.54	1.6±067	1.2±0.088
Guiera senegalensis	0.21±0.068	0.23±0.067	0.16±0.12
Isoberlinia doka	1±0.6	1.4±0.94	3±0.19
Ocimum basilicum	0.53±0.030	0.43±0.061	0.13±0.052
Pilostigma reticulum	0.42±0.023	1.2±0.13	0.6±0.01
Vitallaria paradoxa	0.8±0.25	0.28±0.14	0.7±0.35

Concentration of plants from non-mining site: Cd 1 mg/kg DM (WHO, 2017)

In Table 5. With Cr values of 21±6.27, 18±0.38, and 16±0.38 mg/kg for the root, stem, and shoot, respectively; *A. indica* was found to have the highest levels. The amount of Cr that only *A. indica* and *E. camaldulensis* absorbed was greater than ten times that of plants from uncontaminated environments. Similar to Pb bioaccumulation, no plant met the 100 mg kg -1 criterion for cadmium hyper-accumulation (Hasnaoui *et al.,* 2020; Xing *et al.,* 2020). Compared to their roots and leaves, plants such as *I. doka* had a higher content of Cd in their leaves. This demonstrates that the plants are Cd hyper-bioaccumulators because they can move Cd from the soil through the root and store it in the shoot (Xing *et al.,* 2020). The enrichment coefficient and bioaccumulation factor for Cd in all the tested plants were less than 1. This feature makes these plants very good hyper-bioaccumulators of Cd (Xing *et al.,* 2020). In a lead-zinc mining area in Yunnan Province, China, plants evaluated by Hesami & Ghaderian (2018) found that only one out of over 200 gathered plant species recorded translocation and bioaccumulation factors for Cd > 1. In contrast, the plants from Kataeregi were more effective as Cd hyper bioaccumulators. Furthermore, the Cd concentration in the shoots of none of the studied plants was ten times greater than the background Cd value of plants from an unpolluted environment.

Table 5: Chromium accumulation (mg kg-1) in selected plant tissues extracted from the Kataergi mining site

	Plant parts		
Plant Species	**Root**	**Shoot**	**Leaves**
Azaddiracta indica	21±6.27	18±0.38	16±0.38
Calotropis procera	2.7±2.50	1.3±0.34	1.8±0.38
Eucalyptus camadulensis	17±2.68	16±3.20	13±0.58
Guiera senegalensis	1.3±0.067	1.8±0.067	1.6±0.13
Isoberlinia doka	0.82±0.25	0.4±0.17	0.32±0.29
Ocimum basilicum	3±0.49	4±0.32	2.8±0.15
Pilostigma reticulum	2.±0.14	1.6±0.23	1.4±0.33
Vitallaria paradoxa	2±0.37	1.9±0.033	1.6±0.37

Concentration of plants from non-polluted environments: Cr 10 mg/kg (WHO, 2017)

In Table 6. The Zn concentration of the roots, shoots, and leaves of *E. camaldulensis* and *Vitallaria paradoxa* was found to be the highest at 142±4.8, 107±0.89, 98±0.30, 56±0.30, 93±0.86, and 153.068 mg/kg, respectively. In a similar vein, no plant that was chosen had a zinc accumulation value that was greater than ten times that of plants grown in uncontaminated environments. Compared to the other plants that were taken from Kataeregi, it was discovered that *A. indica* had a larger accumulation of Cr. *A. indica* is an excellent Cr hyper-accumulator, as seen by by the three (3) plants' high Cr content. Since soil concentration of Cr in the soil is so low in comparison to the remaining metals under study, it is likely that none of the plants under analysis reach the hyper-bioaccumulative capacity of Cr of 36 mg kg-1 (Akkus *et al.,* 2017). Because, *A. indica* and *E. camaldulensis* have enrichment coefficients and bioaccumulation factors more than 1, they are considered hyper-accumulators of Cr in environments contaminated with chromium.

Table 6: Zinc accumulation (mg kg-1) in selected plant tissues extracted from the Kataergi mining site

	Plant parts		
Plant Species	**Roots**	**Shoot**	**Leaves**
Azaddiracta indica	94±7.0	89±2.10	72±0.58
Calotropis procera	77±5.10	79±3.30	38±4.10
Eucalyptus camadulensis	142±4.8	107±0.89	98±0.30
Guiera senegalensis	27±0.96	21±0.32	22±0.97
Isoberlinia doka	18±1.90	12.3±0.47	4.6±0.52
Ocimum basilicum	21±0.33	18±2.80	24±3.10
Piliostigmareticulatum	69±1.80	42±1.27	28±2.97
Vitallaria paradoxa	56±0.30	93±0.86	153±0.68

Concentration of plants from non-mining site: Zn 100 mg/kg (WHO, 2017).

In Table 7. All plant species had lower levels of as bioaccumulation in their leaves than the standard reference (WHO, 2017), albeit the levels varied throughout plant species. *Ocimumba silicum* has the greatest as concentration in roots, measuring 11.89±0.01 mg/kg. Three plants had the lowest as concentration in their roots. (*Azadiracta indica*, *Calotropis procera* and *Eucalyptus camaldulensis*) at 0.11 mg/kg which is comparable to the standard of “reference plant” (WHO, 2017). Concentration of As in the stem of *Calotropis procera* was highest at 2.70 mg/kg whilst the lowest was obtained in 3 plant species (*Eucalyptus camaldulensis*, *Guiera senegalensis* and *Isoberliniadoka*) at 0.11 mg/kg. Within the plant leaves, as concentration was highest in *Calotropis procera* at 2.32 mg/kg conversely, *Isoberlinia doka* had the lowest recorded concentration at (0.24 mg/kg). The accumulative quantities of as in the various plant species' Zn is present in high concentrations in the root, stem, and leaves of the samples that were collected. However, similar to Pb, Cd, and Cr, none of the plants that were tested were able to accumulate 10,000 mg kg-1 of Zn, which is necessary for them to be classified as hyper-accumulators of Zn in environments contaminated with Zn (Hasnaoui *et al.*, 2020; Xing *et al.*, 2020). In line with this, plants' capacity to accumulate zinc hyper-bioaccumulatively is further limited because the amount of Zn in their shoots is less than ten times lower than that of plants from uncontaminated settings. On the other hand, some plants may collect more Zn when growing in heavily contaminated areas, as the low concentration of Zn in the plant tissues may be due to a low concentration of the metal in Kataeregi soil. The roots of the plants have a higher rate of metal absorption than other portions of the plant. According to Wu *et al.* (2021) this removal of metals from tissues above ground is referred to as a "metal tolerant strategy." Furthermore, data demonstrated that the plants' ability to withstand heavy metals he plants' ability to withstand heavy metals may be the result of a precautionary approac, primarily involving the immobilizing the metals in the cell walls and roots. Some of the studied plants, such as *A. indica*, *C. procera*, and *E. camaldulensis*, accumulated a high concentration of majority of the metals, suggesting that, in addition to their exclusion mechanisms, they may have an internal metal detoxifying tolerance mechanism. As, Pb, Cd, and Cr are toxic to all plants, however Zn is necessary for plant growth and can become toxic when accumulated in excess by plants (Hasnaoui *et al.*, 2021). This could explain why Zn accumulates more than As, Pb, Cd, and Cr.organs varied, suggesting that organ accumulation was selective in all cases.

Table 8: Arsenic accumulation (mg kg-1) in selected plant tissues extracted from the Kataergi mining site

	Plant Parts		
Plant Species	**Root**	**Stem**	**Leaves**
Azadiracta indica	0.11±0.01	0.52±0.02	1.62±0.03
Calotropis procera	0.11±0.01	2.70±0.02	2.32±0.08
Eucalyptus camaldulensis	0.11±0.01	0.11±0.04	0.83±0.04
Guiera senegalensis	0.42±0.02	0.11±0.00	0.46±0.04
Isoberliniadoka	0.13±0.01	0.11±0.01	0.24±0.23
Ocimum basilicum	11.89±0.01	0.92±0.02	0.74.5±0.03
Piliostigmareticulatum	0.52±0.03	0.60±0.27	0.54±0.02
Vitallariaparadoxa	0.73±0.04	0.2.8±0.02	0.68±0.02

Concentration of plants from non-mining site Pb 5 mg/kg (WHO, 2017).

The bioaccumulation parameters or bioaccumulation indices i.e enrichment coefficient (EF), translocation factor (TF) and bioaccumulation factor (BF), a measure of a plant species' capacity for selective heavy metal accumulation, was found in both organs. i.e root, leaves and the entire plant, including the leaves, with the bioavailable background of Pb, Cd, Cr, Zn and As in soil samples. The mineralization value of the metal that is available to the plant for uptake and a fair assessment to support the plant's accumulative potential are provided by using the bioavailable background concentration. A significant proportion of plant species exhibited selective translocation for the metals (Table 9). Of the plant species, five had translocation factors greater than 1 for Pb (*Guiera senegalensis* had the highest value at 1.54), followed by *Ocimum basilicum*, *Azadiracta indica*, *Eucalyptus camaldulensis,* and *Calotropis procera* (1.34, 1.17, 1.09, and 1.01, respectively). None of the chosen plants in Cd had a bioaccumulation factor or enrichment coefficient greater than 1, but all four plants, *Piliostigma reticulatum, G. senegalensis*, *I. doka,* and *C. procera* had values for translocation factors larger than 1. Parallel to this, in Cr, *A. indica* had the highest enrichment coefficient (1.75), followed by *E. camaldulensis* (1.559); all of these values were higher than 1. However, of the eight selected plant species, translocation factor was larger than one in eight, with *G. senegalensis* having the highest value at 1.385. In *A. indica*, the bioaccumulation factor was higher than 1.In all eight of the chosen plant species, the Zn enrichment coefficient, translocation factor, and bioaccumulation factor were less than one. For as, a plant species produced a bioaccumulation factor more than 1. (*Ocimum basilicum*) in the roots, and 2 plant species (*A. indica*, *C. procera*) in the whole plants. The majority of plant species exhibited metal-specific translocation. Translocation factors greater than 1 was obtained in 4 plant species (*A. indica*, *C. procera*, *E. camaldulensis* and *P.reticulatum*), indicating that they are good phytotranslocators for As.Out of the eight (8) plant species, *Calotropis procera* had the highest TF of 24.55 for As followed by *Azadiracta indica* and *Piliostigma reticulatum* with translocation factors of 4.73 and 1.15 respectively. However, enrichment coefficient was all less than one in all the eight 8 selected plants species. According to (Liu *et al.*, 2019) plants with a high BF value (BF>1) are suitable for phytoextraction or phytoaccumulation. Bioaccumulation factors for as are greater than 1 in only one 1 plant species identified by means of soil-based bioavailable heavy metal concentrations. This suggests that the plants have a strong, specific propensity for absorbing certain metals. Nevertheless, the bioaccumulation factor for none of the plant species was higher than 1 for as in neither stems nor roots (Table 10). According to (Neeraj *et al.*, 2023). The concentration of accessible metal in the soil could serve as a more accurate indicator of the environmental effects of past and present metal pollutants in a contaminated area.

The study clearly supported this assertion that the plants' ability to withstand the selective absorption and accumulative potential was obvious when the concentrations of bioavailable materials are used to calculate the bioaccumulation factor of as in the soil. Thus, there was as bioaccumulation within the root as well as the leaves of *O. basilicum* and *A. indica* repectively. This suggests that, when comparing concentrations within plants to bioavailable forms in soils, the bioaccumulation factor provides a more accurate measure of evaluation for heavy metals extraction in contaminated areas. *Screening of Candidates Plants for Phytoremediation:*

Table 9: Bioaccumulation parameter for bioavailable Pb, Cd, Cr, Zn and As in soil compared to concentrations in plant.

Plant species	**Pb**			**Cd**			**Cr**			**Zn**			**As**		
	EC	**TF**	**BF**	**EC**	**TF**	**BF**	**EC**	**TF**	**BF**	**EC**	**TF**	**BF**	**EC**	**TF**	**BF**
Azadiracta indica	0.063	**1.17**	0.053	0.097	0.765	0.127	**1.75**	0.857	**2.047**	0.457	0.947	0.595	0.047	**4.73**	*0.010*
Calotropis procera	0.082	**1.00**	0.081	0.069	**1.034**	0.067	0.126	0.481	0.263	0.406	**1.026**	0.276	0.209	**24.55**	0.009
Eucalyptus camaldulensis	0.069	**1.09**	0.063	0.012	0.889	0.135	**1.559**	0.941	**1.657**	0.754	0.549	0.692	0.075	**1.00**	0.009
Guiera senegalensis	0.004	**1.54**	0.002	0.017	**1.095**	0.016	0.117	**1.385**	0.127	0.157	0.778	0.162	0.042	0.26	0.038
Isoberliniadoka	0.008	0.67	0.012	0.015	**1.4**	0.075	0.039	0.488	0.079	0.029	0.667	0.059	0.022	0.85	0.012
Ocimum basilicum	0.040	**1.34**	0.038	0.032	0.811	0.039	0.389	**1.333**	0.292	0.857	0.383	0.222	0.068	0.49	**1.073**
Piliostigmareticulatum	0.010	0.52	0.020	0.089	**2.553**	0.031	0.117	0.8	0.195	0.216	0.609	0.35	0.049	**1.15**	0.047
Vitallariaparadoxa	0.006	0.96	0.007	0.021	0.35	0.059	0.185	0.95	0.195	0.479	0.790	0.232	0.061	0.38	0.066

***Key: EC** = Enrichment Coefficient, **TF** = Translocation Factor, **BF** = Bioaccumulation Factor. Values >1 are in bold font*

Table 10: Selection criterion for phytoremediation candidate's plants

Pl	**Plant Species**	**Hyper-accumulation Level of 1000 mg/kg for Pb**	**10–500 times more Pb than Plants from Uncontaminated Environ**	**Enrichment coefficient or translocation factor >1**	**More Pb in shoots than root**	**Score**
Az	*Azadiracta indica*	X	✓	✓	✓	$^{3}/_{4}$
N	*Calotropis procera*	X	✓	✓	✓	$^{3}/_{4}$
	Eucalyptus camaldulensis	X	✓	✓	✓	$^{3}/_{4}$
	Gueieraiera senegalensis	X	X	X	✓	$^{1}/_{4}$
	Isoberlinia doka	X	X	X	✓	$^{1}/_{4}$
	Ocimum basilicum	X	✓	✓	✓	$^{3}/_{4}$
Pi	*Pilostigma reticulum*	X	X	X	✓	$^{1}/_{4}$
V	*Vitallaria paradoxa*	X	X	X	✓	$^{1}/_{4}$

Key: X = Fail, ✓ = Pass

Table 10 demonstrated the assesment used to choose which of the three candidate plants to employ for the remediation analysis. Since *A. indica*, *C. procera*, *O. basicum*, and *E. camaldulensis* met three of the four criteria, they were chosen to serve as test plants for the remediation exercise that would be carried out on Kataeregi's contaminated and control soil. Since *O. basilicum* is an edible plant, it was removed. The concentration of bioavailable heavy metal, which is used in this study to determine the bioaccumulation factor and subsequently the translocation factor, is a better indicator of past and present metal discharges in a contaminated area (Neeraj *et al.*, 2023). This realization of the plants' effective potential to accumulate these heavy metals is made possible. Heavy metal-tolerant species with low TF and high BF (i.e., the ratio of plant root to soil metal concentration) can be utilized in conjunction with vegetative cover to phytostabilize contaminated sites, according to Boi *et al.* (2023). It has already been noted by Bakshe and Jugade (2023) that plants typically use this strategy, known as phytostabilization, to immobilize harmful metals in contaminated soil. The selection criterion for the three candidate plants to use for the remediation analysis. *A. indica*, *C. procera*, *O.basilicum* and *E. camaldulensis* have passed three out of the four criterion used and were therefore selected as the test plants for the restoration exercise to be carried out on both contaminated and control soil of Kataeregi. However, *O. basilicum* is an edible plant and so, it was dropped. According to the previously indicated criteria, *A. indica*, *C. procera*, *O. basilicum*, and *E. camaldulensis* were the most successfully collected autochthonous plants. They met three (3) of the four (4) criteria used. Given that edible and harvestable plant portions can accumulate heavy metals, it is not recommended to pursue phytoremediation research on all food plants (Singh *et al.*, 2024). Consequently, *A. indica*, *C. procera, and E. camaldulensis* were chosen for the phytoremediation study, and *O. basilicum* was not chosen because it is a vegetable that is consumed.

Conclusion: The study provides baseline information of the soil heavy metal profile in the artisanal gold mining site and heavy metal bioaccumulation potential by selected indigenous plants. Out of five heavy metals studied lead (Pb) content of the soil was found to be significantly above the permissible limit indicating substantial contamination. The native plants namely *A. indica*, *C. procera*, *E. camaldulensis* collected around gold mining site show capacity to absorb and accumulate metals from their surroundings. The Pb contents of the plants shoots was found to be higher than those of plants collected from non-mining sites indicating the plants were good hyperaccumulators. The communities around the mining sites must be made aware of the buildup of metals in their surrounding vegetation in order to stay away from the area's edible and medicinal plants. Overall, the three plants examined had bioaccumulation potential for phytoremediation thus, further research on enhancing their phytoremediation potential should be encouraged.

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