

# Spatial Distribution and Bioaccumulation of Selected Heavy Metals by *Pennisetum Purpureum* Grown on an Abandoned Gold Mine Dump in Western Kenya

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## ABSTRACT

Soils in gold mining areas are threatened by heavy metal contamination, posing a great danger to the environment and to both animal and human health. This study was aimed assessing the uptake and bioaccumulation of Cu, Pb, Cd, and Zn, in *Pennisetum purpureum* grown on a gold mine dump in western Kenya. Soil and plant samples were randomly collected from four points on the mine dump in March 2024. The control samples were collected away from the mine dump. The samples were collected in triplicate and air-dried for two weeks. The plant samples were separated into the different parts, and with soil samples, they were each separately ground into fine powder. 50 g of each set of replicates was combined to form a composite sample. The samples were digested and the levels of the metals were determined using atomic absorption spectroscopy. The amount each metal in the samples from the mine dump was higher than the WHO permissible levels for agricultural soils and plants. The quantities of the heavy metals in the soil and plants were in the order Cd<Pb<Zn<Cu. The metal levels in the plants were, Cu: soil>roots>leaves>stem, Pb: soil>leaves>roots>stems, Cd: soil>stems>roots>leaves, and Zn: soil>roots>stems>leaves. Synergistic interactions were observed between the quantities of the different metals in the soils and in different plant parts. Although *P. purpureum* samples from the mine dump were contaminated by Pb, Cu, Zn, and Cd, hence unfit for livestock consumption, the crop has great potential for phytoremediation of the heavy metal in contaminated soil.

**Keywords:** *Pennisetum purpureum*, translocation, accumulation, bioconcentration, heavy metals.

## INTRODUCTION

Soils in areas where gold mining activities are prevalent are increasingly threatened by heavy metal contamination, presenting severe ecological and public health problems. Heavy metal contamination has been a global concern over the years especially in those countries that rely on mining as their main source of income (Neyole, 2005). Although mining is a worldwide economic activity that has provided employment directly to millions of people in numerous countries (World Gold Council, 2013), it is also a hazardous activity that greatly impacts on agricultural soils and aquatic systems (Neyole, 2005). Mines contain elevated concentrations of heavy metals like Cr, As, Pb, Ni, Cu, Zn and Cd, which are deposited on surface soil during extraction and processing. These metals are of concern because they are persistent, non-biodegradable and potentially bioaccumulate in food chain posing a threat to the ecosystem and human health (Adiloglu, 2017; Juel et al., 2021). The heavy metals are absorbed from soil by plants, biomagnified and bioaccumulate in their tissues. Animals, including livestock are exposed to the heavy metals via feeding on contaminated plants or drinking contaminated water. These metals then reach the humans through consumption of contaminated plants, or animal products or even through drinking contaminated water (Ali & Khan, 2018). Heavy metals are

detrimental to both animal and human health, and are associated with many issues such as infertility, brain damage, cancers, embryo defects among others (Hapke, 1991).

In Africa, mine tailings, dumps and abandoned mines are a common sight in many areas where gold mining

has been practiced over time in numerous countries including South Africa, Ghana, Democratic Republic of Congo, among others (Ogola et al., 2002; Olobatoke & Mathuthu, 2016; Gankhuyag & Gregoire, 2018). In Tanzania, Uganda and Kenya, gold mining activities have been intensively practiced around Lake Victoria basin (Ogola et al., 2002). The ecological health of the lake has thus been severely affected by a combination of degrading processes including deposition of mining effluents. In most of these areas the soil was found to exhibit physico-chemical parameters and levels of heavy metals that were above acceptable limits (Ogola et al., 2002; GOK, 2016; Shikanga, 2024). Some of the heavy metals associated with gold mining activities include Pb, Cu, Cd, Cr, Fe, Mn, Hg, and As (Ogola et al., 2002; Olobatoke & Mathuthu, 2016; Shikanga, 2024).

In Kenya, commencement of gold mining dates back to the early 19<sup>th</sup> century and these activities are concentrated mainly around Lake Victoria basin which has been reported to possess considerable amounts of underexploited and underexplored gold reserves (GOK, 2016; Gankhuyag & Gregoire, 2018). Gold mining has been practiced in Turkana, West Pokot, Baringo, Vihiga, Kakamega, Siaya, Kisumu, and Migori counties (Ogola et al., 2002; Arasa et al., 2020; Ondayo et al., 2023; Shikanga, 2024). Monitoring environmental violations in Kenya has been difficult due to lack of resources and widely scattered, and inaccessible nature of gold mining practices. In Migori Gold Belt, mine tailings, dumps and soils near abandoned mines were found to have concentration of heavy metals mainly Cd, Pb, Hg, and As, which were above acceptable levels (Ogola et al., 2002; Arasa et al., 2020).

Heavy metals present an unacceptable risk to humans, animals and the environment. Rehabilitation of soil contaminated with heavy metals is necessary before it is converted for agricultural purposes. Plants growing on soils contaminated with heavy metals accumulate them by absorbing them from the soil through roots and translocating them to the aerial parts including stems, barks, leaves, flowers, fruits and even seeds (Hesami et al., 2018). Bioaccumulation of heavy metals by plants can be evaluated using bioconcentration factor (BCF) which is ratio of movement of metals ions from soil to different plant parts, translocation factor (TF), a ratio indicating movement of the metals ions from the roots to aerial parts (Sun et al., 2008; Shafie et al., 2013; Hesami et al., 2018), and metal accumulation indices (MAI), which is used to evaluate the overall performance of heavy metal accumulation in the plants (El-Amier et al., 2018). Plants are classified into three groups (metal excluders, indicators, or hyperaccumulators) depending on their rates of accumulation of heavy metals from the soil (Baker et al., 2000). Metal excluders comprise of plants that accumulate high level of metals in the roots but prevent them from reaching the shoots (Sun et al., 2008; Hesami et al., 2018). Metal indicators constitute plants in which the presence and concentration of heavy metals indicate their presence and quantities in the soil. The presence of high levels of the specified metal in the plant is a reflection of soil contamination by that particular heavy metal. Both the BCF and TF of a particular element in a metal excluder or indicator are usually  $< 1$ . Hyperaccumulators include plants that absorb and accumulate exceedingly high levels of one or more heavy metals in the shoots without being destroyed (Hesami et al., 2018). The BCF and TF values for hyperaccumulators are usually  $> 1$ , indicating strong potential for phytoextraction (Chamba-Eras et al., 2022).

Different parts of plants are used by humans and animals for different purposes including food, cosmetics and medicine. Accumulation of heavy metals in these plant parts exposes the consumers to detrimental effects of the metals. *Pennisetum purpureum schumach.* (Poaceae), commonly referred to as Napier grass is one of the important perennial tropical forage crops which is native to African grassland but is now grown in many tropical countries (Haegele et al., 2017). It has low water and nutrients requirements and therefore can make use of otherwise uncultivated land (Juel et al., 2021). It is majorly cultivated for use as feed for livestock and can also be dried into hay or silage, and used as fodder crop for livestock during the dry season. It is also planted in marginal areas to increase soil fertility and reduce soil erosion due to its long, deep root system, resistance to an extensive variety of unfavorable climatic and edaphic conditions (Juel et al., 2021).

In Migori County, apart from gold mining, majority of the residents practice small scale farming of food crops including sugarcane, maize, millet and vegetables as well as fish and livestock farming (Ogola et al., 2002; Arasa et al., 2020). Numerous crops including maize, vegetable crops and *P. purpureum* are grown on abandoned mines, mine tailings and dumps, many of which are close to rivers and wetlands for sustainability even during the dry season. *P. purpureum* is used by the farmers to feed their livestock including cows, sheep and goats, and also for selling to generate income. This plant is grown on soils potentially contaminated by mining activities and fed to animals which are sources of milk and meat, to the local populace. Uptake and accumulation of heavy metals in the *P. purpureum* could potentially result in transfer of the metals to humans through the animal products they consume. It is therefore necessary to evaluate the heavy metal uptake and bioaccumulation capacity of *P. purpureum* grown on soil contaminated by gold mining activities in order to ascertain its safety for use as livestock feed.

## METHODOLOGY

### Sample collection and pretreatment

The *P. purpureum* and soil samples were collected from an abandoned mine dump in Masara area in Migori County, western Kenya. The area lies within latitude 1° 1' 59" S and longitude 34° 19' 59" E and is characterised with a tropical monsoon climate which is suitable for the growth of *P. purpureum*. The main economic activities in the region are mining (done by excavation) and small scale farming of both crops and livestock (Arasa et al., 2020; Odayo et al., 2023). Sampling of soil and plants was conducted during short rains in March 2024. Three-month-old *P. purpureum* plants were collected from four randomly selected points (Point P1- P4) on the mine dump while soil samples were collected at the point of plant collection at a depth of 30 cm using a soil auger. The soil and plant samples were collected in triplicate from each point. Control samples were collected 1 Km away from the gold mine where gold mining activities have never been practiced. After collection, both the soil and plant samples were packed in plastic bags and transported to the labs for analysis. The plant samples were then separated into leaves, stems and roots, and washed with distilled water. Both the soil and plant parts were air dried in the sun for a period of two weeks. Each of the dried plants' parts were chopped into small pieces with a clean scalpel and pulverised into fine powder <100 µm using a pulverising disk machine. Soil samples were also pulverised into fine powder <100 µm. The replicate samples from each point were combined to form a single composite sample.

### Sample digestion and heavy metal analysis

A 10 g portion of each of the composite samples and the controls was placed in 500 mL beaker and 10 mL of concentrated HNO<sub>3</sub> were added. Each beaker was covered with a watch glass and allowed to stand overnight. The samples were then heated at about 125°C and refluxed for about 15 minutes without boiling and thereafter cooled to room temperature. About 5 mL of concentrated HNO<sub>3</sub> was added to each sample and refluxed further for 30 minutes. This was done repeatedly until no brown fumes were observed indicating complete reaction with HNO<sub>3</sub>. Each sample was then allowed to evaporate to approximately 5 mL solution without boiling. The remaining mixtures were then cooled, followed by addition of 10 mL of deionized water and 15 mL of 30% hydrogen peroxide (H<sub>2</sub>O<sub>2</sub>). The samples were then warmed to initiate the peroxide reaction with continued addition of 30% H<sub>2</sub>O<sub>2</sub> until their appearance remained unchanged. Thereafter, dilute HNO<sub>3</sub> and deionised water were added in the ratio of 1:2 to dissolve the residue and bring the sample to a final volume at 50 mL. Finally, the samples were filtered and the filtrates preserved for analysis of Pb, Cu, Cd and Zn using an atomic absorption spectrophotometer (AAS) in triplicate. Five standard dilutions of each metal were prepared and analysed using AAS for preparation of the calibration curves for the different metals.

### Quality Control

To ascertain reliability of the analysis, deionized water was used throughout and all reagents used were of AR grade. Preparation of calibration curves and confirmation of the actual concentrations of the metals using AAS was achieved by analysis of calibration standards for each heavy metal. Corrections to the instrument readings were performed using reagent blanks. Precision of the data was determined by conducting replicate analyses.

Recovery data for each analyte was evaluated by spiking or standard addition method in accordance to ICH (2005). Ground samples comprising of soil, roots, stem and leaves of *P. purpureum* collected from Point 2 (P2) on the mine dump were each subdivided into four portions, each weighing 2.00 g. The first portion was spiked with a mixture of the four standards (Cu, Pb, Cd and Zn), each at a concentration of 5.0 µg/mL while the remaining two were spiked with the standard mixture at 10.0 and 20.0 µg/mL of each heavy metal respectively. The spikes represented low, medium and high concentration of each standard. The fourth portion was used as the control sample hence was not spiked with the standard mixture. All the samples were then digested as described in Section 2.2 and analysed in triplicate using AAS. The recovery of each standard was expressed as the percentage concentration of the heavy metal recovered against the concentration of the relevant spike.

**Data Analysis**

Statistical analysis of data including calculation of means and standard deviation (SD) of replicate analyses,

linear regression analysis, and one-way analysis of variance (ANOVA, single factor without replication) tests, were performed using Microsoft Excel version 2013. ANOVA, single factor without replication and LSD tests were applied to the data, and the results with  $p \leq 0.05$  were considered to be significantly different. Pearson correlation was used to determine the effect of uptake of an element by the plant on the other. Bioconcentration factors (BCF) and translocation factors (TF) were determined using equations (i) and (ii) respectively (Hesami et al., 2018; Sun et al., 2008; Shafie et al., 2013).

$$BCF = \frac{C_{organism\ tissue}}{C_{abiotic\ medium}} \dots\dots\dots \text{Equation (i)}$$

Where  $C_{organism\ tissue}$  is the concentration of a heavy metal in the tissue of an organism (roots, stem and leaves) and  $C_{abiotic\ medium}$  is the concentration of the heavy metal in the abiotic medium (water, sediments or soil).

$$TF = \frac{C_{aerial\ part}}{C_{roots}} \dots\dots\dots \text{Equation (ii)}$$

Where  $C_{aerial\ part}$  is the concentration of the heavy metal in the shoot tissues (stem and/or leaves) and  $C_{roots}$  is the concentration of a heavy metal in the roots of the plant.

The metal accumulation index (MAI) was used assess the overall metal accumulation capacity of plants and was determined using equations (iii) and (iv) (Liu et al., 2007).

$$MAI = \sum_{j=1}^N I_j \dots\dots\dots \text{Equation (iii)}$$

$$I_j = \frac{\bar{x}}{\sigma} \dots\dots\dots \text{Equation (iv)}$$

Where N is the total number of metals analysed and  $I_j$  is the sub-index for variable j,  $\bar{x}$  is the mean concentration of an element and  $\sigma$  is its standard deviation.

**RESULTS AND DISCUSSION**

**Quality control**

Calibration curves for the four heavy metals were linear with  $R^2$  values of 0.996, 0.989, 0.993, and 0.997, for Pb, Cu, Cd, and Zn respectively, thus appropriate for determination of the quantities of the heavy metals in the soil and plant samples. Data obtained from recovery analyses of both spiked and unspiked soil, root, stem and leaf samples of *P. purpureum* from point 2 on mine dump is highlighted in Table 1. The recovery values for Pb, Cu, Cd and Zn, were within the acceptable range (80-120%) considered ideal for recovery studies of heavy metals in substances (ICH, 2005).

Table 1: Data from recovery studies for Pb, Cu, Cd and Zn in soil and different parts of *P. purpureum* samples

Sample	Analyte	Sample content (µg/mL)	Spike (µg/mL)	Sample + spiked content (µg/mL)	Recovery content (µg/mL)	%Recovery
Soil	Cu	123.8	5.0	128.8	4.45±0.02	90.1±0.2
		123.8	10.0	133.8	8.67±0.01	87.3±0.4
		123.8	20.0	143.8	18.56±0.12	93.2±0.1
	Pb	66.5	5.0	71.5	4.81±0.03	95.8±0.6
		66.5	10.0	76.5	9.22±0.06	91.9±0.2
		66.5	20.0	86.5	17.61±0.11	88.4±0.8
	Cd	6.9	5.0	11.9	4.80±0.04	95.7±0.8
		6.9	10.0	16.9	9.53±0.08	94.6±0.5
		6.9	20.0	26.9	17.94±0.14	89.5±0.1
Zn	75.0	5.0	80.0	4.56±0.01	91.6±0.3	
	75.0	10.0	85.0	8.91±0.07	89.1±0.5	
	75.0	20.0	95.0	18.39±0.11	92.3±0.6	
Roots	Cu	113.8	5.0	118.8	4.82±0.02	95.9±0.1
		113.8	10.0	123.8	8.22±0.05	82.3±0.1
		113.8	20.0	133.8	19.01±0.15	95.2±0.3
	Pb	49.0	5.0	54.0	4.55±0.02	90.0±0.5
		49.0	10.0	59.0	9.12±0.05	91.4±0.5
		49.0	20.0	69.0	18.91±0.14	94.5±0.9
	Cd	4.3	5.0	9.3	4.67±0.05	94.3±0.7
		4.3	10.0	14.3	9.56±0.02	96.0±0.2
		4.3	20.0	24.3	19.44±0.09	97.2±0.4
Zn	66.7	5.0	71.7	4.78±0.04	96.2±0.8	
	66.7	10.0	76.7	9.45±0.02	94.9±0.3	
	66.7	20.0	86.7	19.33±0.07	96.5±0.3	
Stem	Pb	16.6	5.0	21.6	4.62±0.01	91.7±0.2

		16.6	10.0	26.6	9.33±0.06	92.6±0.6
		16.6	20.0	36.6	18.94±0.16	94.5±0.5
	Cu	55.7	5.0	60.7	4.78±0.05	95.5±0.8
		55.7	10.0	65.7	8.56±0.08	86.0±0.4
		55.7	20.0	75.7	19.01±0.12	95.1±0.6
	Cd	5.5	5.0	10.5	4.78±0.01	96.0±0.3
		5.5	10.0	15.5	8.91±0.03	89.3±0.2
		5.5	20.0	25.5	18.56±0.12	93.1±0.7
	Zn	68.9	5.0	73.9	4.11±0.01	82.1±0.5
		68.9	10.0	78.9	9.22±0.03	92.4±0.1
		68.9	20.0	88.9	19.31±0.15	96.5±0.2
Leaves	Cu	79.7	5.0	84.7	4.51±0.04	90.0±0.2
		79.7	10.0	89.7	9.55±0.08	96.2±0.6
		79.7	20.0	99.7	18.12±0.14	90.5±0.2
	Pb	55.6	5.0	60.6	4.43±0.05	88.1±0.5
		55.6	10.0	65.6	9.13±0.08	91.2±0.3
		55.6	20.0	75.6	19.67±0.19	98.5±0.7
	Cd	2.1	5.0	7.1	4.78±0.02	96.3±0.1
		2.1	10.0	12.1	8.89±0.02	89.1±0.5
		2.1	20.0	22.1	19.45±0.10	97.5±0.3
	Zn	53.6	5.0	58.6	4.45±0.01	90.2±0.4
		53.6	10.0	63.6	8.78±0.04	88.2±0.1
		53.6	20.0	73.6	19.09±0.13	95.0±0.3

\*Recovery content and %recovery data represent mean±Sd of three replicate analyses.

### Concentrations of Pb, Cu, Cd and Zn in soil and different parts of *P. purpureum* samples

Plants absorb toxic heavy metals from the soil, translocate them via roots to aerial parts including leaves, flowers, seeds and fruits, where they are stored (Ma et al., 2016). The results obtained from analysis of Pb, Cu, Cd, and Zn, in soil and different parts of *P. purpureum* samples obtained from the abandoned mine dump in Masara area, Migori County in western Kenya are presented in Table 2. The levels of the different metals in the soil and plant parts obtained from the mine dump were significantly higher than the corresponding values obtained from those of the controls. Mining activities including excavation and ore processing result in

deposition heavy metals on surface soil which lead to elevated levels of the metals in the affected soils (Sheoran et al., 2011; Ondayo et al., 2023; Shikanga, 2024). The amount of a given heavy metal absorbed from the soil by *P. purpureum* depended on the concentration of the specified metal in the soil.

Table 2: Levels of Pb, Cu, Cd and Zn in soil, roots and aerial parts of *P. purpureum* samples

Sampling Point	Sample	Concentration mg/kg of Dry weight			
		Pb	Cu	Cd	Zn
Control	Soil	Nd	0.16±0.01a	Nd	2.42±0.16a
	Roots	Nd	0.13±0.01b	Nd	2.21±0.05a
	Stems	Nd	0.07±0.02c	Nd	1.96±0.09a
	Leaves	Nd	0.02±0.01d	Nd	1.03±0.04b
Point 1	Soil	163.68±9.25a	210.13±11.27e	13.88±3.77a	201.32±9.84c
	Roots	117.11±6.36b	154.68±10.59f	3.56±0.85b	164.66±5.64d
	Stems	32.94±3.81c	70.13±5.87g	5.74±1.42b	142.00±5.66e
	Leaves	135.03±8.36d	126.40±8.00h	1.48±0.21c	71.66±4.74f
Point 2	Soil	332.58±9.14e	618.92±20.68i	34.47±5.35d	375.18±37.74g
	Roots	244.78±13.39f	569.20±18.88j	21.70±3.27e	333.30±25.00g
	Stems	82.93±7.06g	278.26±12.94k	27.32±2.83e	324.28±20.01g
	Leaves	278.08±18.36h	398.46±10.29l	10.30±3.14a	268.23±15.67h
Point 3	Soil	365.80±20.83i	571.74±20.87j	30.06±1.91e	413.79±20.87i
	Roots	303.93±10.10h	434.02±15.39k	12.02±3.68a	351.12±14.98g
	Stems	50.09±6.25j	341.15±10.16l	20.11±6.38e	295.43±12.01j
	Leaves	330.64±12.3li	384.26±8.86m	6.33±0.64b	266.43±3.87h
Point 4	Soil	318.14±12.44il	612.67±20.62i	35.99±4.17d	402.51±10.41i
	Roots	244.35±15.21h	563.20±20.60j	17.02±2.72e	372.40±22.26g
	Stems	92.55±9.82g	301.89±10.48k	25.01±5.94e	313.71±16.05j
	Leaves	268.44±19.73h	260.95±9.63k	4.27±0.25b	268.53±10.97h
WHO Permissible Limits (WHO, 1996)	Soil	85.0	36.0	0.8	50.0
	Plants	2.0	10.0	0.02	0.6

\*Data in the table represents mean±Sd of triplicate analyses. \*\*Values followed by same letter in every column are not significantly different (p>0.05). †Nd= Not detected.

The levels of the different heavy metals were beyond the maximum acceptable limits in soil and plants according to WHO (1996) (Table 2) implying that the surface soil on which *P. purpureum* was cultivated had been contaminated by the heavy metals. The concentration of Cu was highest in the soil collected from different sections of the mine dump followed by Zn, then Pb, while Cd was least ( $p \leq 0.05$ ). The amounts of each heavy metal in the different plant parts were in the order  $Cd < Pb < Zn < Cu$ , which corresponded to the concentrations of the different elements in the soil samples. The quantity of Pb was lowest in the stem samples, followed by roots and highest in the leaves. This trend was similar to that obtained by Singh (2025) for *P. purpureum* grown on sediments obtained from Gomti River in India and Juel et al. (2021) for plants growing on sludge from a leather tannery in Bangladesh. For Cu, the highest levels were observed in the roots, followed by leaves and lowest in the stem parts. The concentration of Cd in the different plant parts was in the order  $leaves < roots < stem$ , while accumulation of Zn in the different parts of the plant followed the order  $roots > stem > leaves$ . In all cases the levels of a specified element in the soil samples was higher than that observed in each of the different parts. The trends for accumulation of Cu and Zn in the different *P. purpureum* were similar as those obtained by Juel et al. (2021) and Singh (2025).

Even though Cu is an essential element required for plant growth, elevated concentrations of the element ( $>100$  mg/kg) has been observed to be lethal to plant growth (Yau & Murphy, 2000). *P. purpureum* is a Cu tolerant plant because it was observed to accumulate high levels ( $>100$  mg/kg) without much effect on the plants growth. Just like *Cyperus rotundus*, a grass which has been reported to be tolerant to high Cu stress levels of equal to or greater than 300 mg/kg (Okurut. 2002; Jahan-Nejatiet al., 2021; Shikanga, 2024), *P. purpureum* was observed to accumulate upto  $618.92 \pm 20.68$  mg/kg of Cu without being affected. The proportion of a specified heavy metal absorbed and stored by *P. purpureum* depends on the levels in the soil where the plant grows. Just like Cu, Zn is an essential trace metal which is harmless although exposure to high amounts have been reported to cause toxic effects including aptosis, reduced Cu uptake, ischemia or trauma (Plum et al., 2010).

**Bioconcentration and translocation factors of Pb, Cu, Cd and Zn in soil and *P. purpureum* samples**

Bioaccumulation of heavy metals by a plant may be determined by its bioconcentration factor (BCF) and translocation factor (TF) (Sun et al., 2008; Shafie et al., 2013; Hesami et al., 2018). BCF is a ratio used to assess the ability of a plant to accumulate metals from substrates such as soil and water (Ghosh & Singh, 2018), while TF is used to evaluate mobility of heavy metal from the roots to aerial parts of a plants (Hesami et al., 2018). The BCF and TF values for Pb, Cu, Cd and Zn in roots, stems and leaves of *P. purpureum* relative to corresponding soil samples are presented in Table 3.

Table 3. Bioconcentration factors and translocation factors for Pb, Cu, Cd and Zn in different parts of *P. purpureum* samples.

Heavy metal	Sampling Point	BCF			TF	
		Roots/Soil	Stems/Soil	Leaves/Soil	Stems/Roots	Leaves/Roots
Pb	C	-	-	-	-	-
	P1	$0.72 \pm 0.05a$	$0.20 \pm 0.03a$	$0.83 \pm 0.10a$	$0.22 \pm 0.06a$	$1.16 \pm 0.18a$
	P2	$0.73 \pm 0.07a$	$0.25 \pm 0.04a$	$0.84 \pm 0.05a$	$0.34 \pm 0.08a$	$1.14 \pm 0.13a$
	P3	$0.72 \pm 0.10a$	$0.22 \pm 0.02a$	$0.82 \pm 0.04a$	$0.27 \pm 0.04a$	$1.12 \pm 0.09a$
	P4	$0.74 \pm 0.03a$	$0.29 \pm 0.05a$	$0.86 \pm 0.03a$	$0.38 \pm 0.07a$	$1.11 \pm 0.19a$
Cu	C	$0.79 \pm 0.04a$	$0.44 \pm 0.04b$	$0.12 \pm 0.02b$	$0.56 \pm 0.08b$	$0.15 \pm 0.03b$

	P1	0.92±0.04b	0.37±0.04b	0.66±0.02c	0.66±0.04b	0.40±0.04c
	P2	0.92±0.01b	0.45±0.06b	0.64±0.01c	0.64±0.04b	0.45±0.02c
	P3	0.86±0.05b	0.50±0.03b	0.67±0.03c	0.59±0.08b	0.44±0.03c
	P4	0.92±0.05b	0.49±0.04b	0.53±0.07c	0.54±0.06b	0.46±0.01c
Cd	C	-	-	-	-	-
	P1	0.46±0.06c	0.41±0.05b	0.11±0.05b	1.63±0.33c	0.44±0.13c
	P2	0.53±0.06c	0.49±0.10b	0.14±0.05b	1.56±0.04c	0.47±0.12c
	P3	0.40±0.10c	0.45±0.17b	0.15±0.01b	1.67±0.02c	0.52±0.12cd
	P4	0.47±0.07c	0.47±0.05b	0.12±0.01b	1.46±0.13c	0.46±0.05c
Zn	C	0.91±0.08b	0.86±0.10c	0.80±0.07a	0.94±0.02d	0.88±0.05e
	P1	0.88±0.04b	0.80±0.05c	0.59±0.03c	0.91±0.02d	0.69±0.06f
	P2	0.91±0.25b	0.81±0.10c	0.62±0.09c	0.89±0.04d	0.72±0.03f
	P3	0.85±0.10b	0.71±0.08c	0.64±0.01c	0.84±0.05d	0.76±0.08f
	P4	0.90±0.11b	0.78±0.06c	0.67±0.05c	0.88±0.17d	0.75±0.09f

\*Values represent mean±Sd of three replicate analyses. \*\*Values followed by same letter in every column are not significantly different ( $p>0.05$ ). †C: control site, ‡P1-4: points of sampling on the mine dump

The BCF values for Cu in the roots were not significantly different to those of Zn ( $p>0.05$ ). However, these values were higher than those for Pb which were subsequently higher those for Cd ( $p>0.05$ ). This implies that the roots had higher capacity to accumulate Cu and Zn in comparison to Pb and Cd. The BCF values for the stem samples were in the order Zn>Cu=Cd>Pb, indicating that the stem samples of *P. purpureum* had higher capacity to accumulate Zn compared to the other three metals. The capacity of the leaves to store the metals followed the order Pb>Cu=Zn>Cd, an indicator that leaves had the strongest ability to accumulate Pb and a weakest capacity to store Cd. The rates of translocation expressed as TF of the metals from the roots to the stems of the plants were in the order Cd>Zn>Cu>Pb, while the order for roots to leaves was Pb>Zn>Cu=Cd. This implied that Cd exhibited the highest capacity in terms of translocation of the metals to the stem from roots while Pb possessed the highest capacity in terms of translocation from the roots to leaves.

The BCF and respective TF values of Pb for each of the specified parts collected from different parts of the mine dump were not significantly different ( $p>0.05$ ). The BCF values for Pb metal were highest for the leaves, followed by the roots and lowest for the stem samples. This affirms the findings on Table 2, that *P. purpureum* accumulates higher quantities of Pb in the leaves and roots compared to the stems. The TF values of Pb in the leaves are greater than in the stems indicating that the leaves store higher amounts of Pb than the stems. Just like for Pb, the BCF and TF values of Cu for the root, stem and leaf samples from plants collected from different points on the mine dump respectively, did not differ significantly ( $p>0.05$ ). From the data in Table 1, the levels of Cu in soil and different plants parts differed significantly ( $p<0.05$ ) depending on concentration at the point of collection on the mine dump. However, rate of accumulation of Cu by the plant was in the order roots>leaves>stems. This could imply that the capacity to accumulate Cu from the soil was highest for the roots and lowest for stems. The TF values of Cu for the stems and leaves show that the ability of *P. purpureum* to translocate Cu from the roots to stems was higher compared to that of roots to the leaves. The BCF and TF values of Cd for the different plant parts of *P. purpureum* samples did not differ significantly ( $p>0.05$ ).

Although the concentration of Cd in soil and different plants parts varied significantly ( $p < 0.05$ ) depending on the point of collection on the mine dump (Table 2), the order of the rate of accumulation of Cd by roots and stems were not significantly different ( $p > 0.05$ ), but were greater than those of the leaves ( $p < 0.05$ ). This means that the capacity to accumulate Cd from the soil was highest for the roots and stems compared to the leaves. Based on the TF results in Table 3, the ability of *P. purpureum* to translocate Cd from the roots to stems was higher than that of roots to leaves as expressed by Hesami et al. (2018). The BCF and respective TF values of Zn for each of the specified plant parts collected from different parts of the mine dump were not significantly different ( $p > 0.05$ ). Although the amounts of Zn accumulated in different parts of *P. purpureum* plants depended on the quantities available in the soil, the rate at which the plant stores Zn does not depend on the concentration of the metal in the soil. Just like for Cd, the BCF values for Zn were similar for the roots and stems ( $p > 0.05$ ). These values were higher than those of Zn for leaves ( $p < 0.05$ ). The TF values of Zn for the leaves were not significantly different from those of the stems implying that the rate of translocation of Zn from roots to stem and roots to leaves is similar. *P. purpureum* may be categorised as an indicator plant since the concentration of the heavy metals in the soil is reflected in the different plant parts (Baker et al., 2000).

### Metal accumulation indices of selected heavy metals in *P. purpureum*

The MAI values for *P. purpureum* samples collected randomly from different points on the gold mine dump are expressed in Figure 1. The MAI value for the plants obtained from the control site was approximately ten times much lower than those of the plants collected from the different points on the mine dump. These results indicate that *P. purpureum* plants growing soil contaminated by gold mining activities are enriched in heavy metals in comparison with those growing on unpolluted soil. These results were in agreement with the findings of similar studies by Hu et al. (2014) and Shikanga (2024) who observed that *C. rotundus* grass growing on contaminated soils had higher MAI values compared to those growing on unpolluted soil. The MAI values for the samples obtained from the different points on the mine dump did not differ significantly from each other ( $p > 0.05$ ). Although high MAI values are vital in disqualification of the plant from consumption as animal feed or human food, they are good indicators for plants species selection for phytoremediation of contaminated soil (Hu et al., 2014). Therefore, *P. purpureum* has great potential for use in remediation of soil polluted by Pb, Cu, Cd and Zn, from gold mining activities.

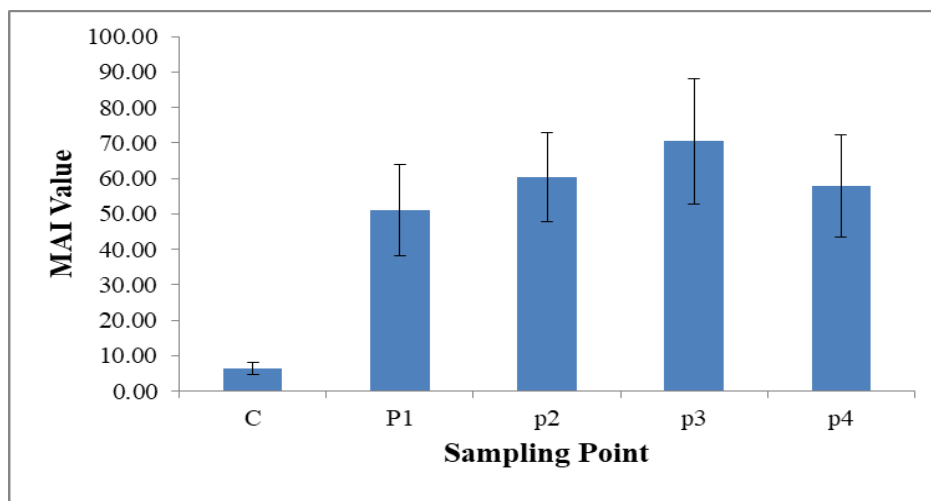


Figure 1. The MAI values Cu, Pb, Zn and Cd, for *P. purpureum* samples collected from an abandoned gold mine dump.

### Correlation of levels of the heavy metals in the soil and in different parts of *P. purpureum*

Data from correlation studies indicate that the levels of the heavy metals in the roots, stems and leaves of *P. purpureum* were correlated with those in the corresponding soil samples to varying degrees (Table 4).

Table 4. Correlation matrix for levels Pb, Cu, Cd and Zn in the soil and different parts of *P. purpureum*

	PbS	PbR	PbSt	PbL	CuS	CuR	CuSt	CuL	CdS	CdR	CdSt	CdL	ZnS	ZnR	ZnSt	ZnL
PbS	1.00															
PbR	0.99	1.00														
PbSt	0.89	0.48	1.00													
PbL	0.97	0.99	0.46	1.00												
CuS	0.84	0.89	0.81	0.88	1.00											
CuR	0.69	0.76	0.92	0.75	0.97	1.00										
CuSt	0.95	0.59	0.62	0.87	0.95	0.85	1.00									
CuL	0.89	0.38	0.47	0.70	0.85	0.75	0.85	1.00								
CdS	0.76	0.82	0.89	0.80	0.98	0.99	0.90	0.77	1.00							
CdR	0.58	0.64	0.90	0.64	0.90	0.96	0.63	0.75	0.92	1.00						
CdSt	0.72	0.27	0.89	0.77	0.97	0.79	0.76	0.71	0.98	0.97	1.00					
CdL	0.64	0.34	0.54	0.67	0.75	0.74	0.54	0.81	0.70	0.85	0.80	1.00				
ZnS	0.93	0.96	0.68	0.95	0.96	0.88	0.99	0.83	0.93	0.76	0.89	0.63	1.00			
ZnR	0.89	0.53	0.75	0.92	0.98	0.92	0.78	0.71	0.96	0.81	0.72	0.54	0.99	1.00		
ZnSt	0.80	0.44	0.73	0.74	0.88	0.87	0.70	0.77	0.97	0.95	0.69	0.73	0.92	0.94	1.00	
ZnL	0.89	0.23	0.66	0.82	0.89	0.84	0.87	0.76	0.97	0.86	0.75	0.63	0.98	0.99	0.97	1.00

\*n=64, \*\*p=0.05. †Pb<sub>S</sub> (conc of Pb in soil), Pb<sub>R</sub> (conc of Pb in roots), Pb<sub>L</sub> (conc of Pb in leaves), Cu<sub>S</sub> (conc of Cu in soil), Cu<sub>R</sub> (conc of Cu in roots), Cu<sub>L</sub> (conc of Cu in leaves), Cd<sub>S</sub> (conc of Cd in soil), Cd<sub>R</sub> (conc of Cd in roots), Cd<sub>L</sub> (conc of Cd in leaves), Zn<sub>S</sub> (conc of Zn in soil), Zn<sub>R</sub> (conc of Zn in roots), Zn<sub>L</sub> (conc =-of Zn in leaves). ‡Concentrations are in mg/kg of dry weight.

There was moderate to strong positive correlations between the levels of each heavy metal in the different soil samples collected from the mine dump. This implies that the heavy metals are present in all the soil samples collected on the mine dump in similar proportions indicating a common anthropogenic origin. Moderate to strong positive correlations were observed between the levels of each heavy metal in the soil and corresponding plant parts. This suggests that the relative quantities of each heavy metal in the different parts of *P. purpureum* is proportional to the concentration of that specified metal in soil samples obtained from the same point. Strong positive correlations were also observed for the concentration of each heavy metal in the soil and corresponding roots samples of plants obtained from the same point. Similar trends were observed for correlation between the levels of the heavy metals in the stem and leaves samples. This indicates that synergistic interactions were present between the different metals in the soils and in different plant parts. The mobility and accumulation of a specified metal in a growth medium usually depends on the competition between the different ions in the system (Kisten et al., 2015).

Plants with a high ability to translocate and accumulate heavy metals to the edible organs (metal accumulators) are not suitable for human food or animal feed production especially when cultivated in areas where soil is contaminated. Although Cu and Zn are essential elements in plant growth, consumption of elevated amounts of Cu by humans have been reported to cause nerve damage, stomach upset, sickness, and diarrhea (Nirola et al.,

2015). Whereas Pb causes damage to the brain and renal system, and it can also result in neurological and hematological defects (Bharti & Sharma, 2021), Cd has been associated with lung damage, kidney diseases, reproductive defects, and defects in the growing foetus (Moore et al., 2015). A study by Shen et al. (2019) on investigation of heavy metal poisoning in sheep living on pastures in the vicinity of a smelting facility in China, observed that heavy metal contamination caused harm to sheep, and posed a significant risk to humans living in the vicinity of the smelting facility. *P. purpureum* growing on soil contaminated by gold mining activities is therefore unfit for animal consumption since accumulation of these metals in animal products including meat and milk could pose risk to humans since they are transferred to human tissues upon consumption of the contaminated food.

## CONCLUSIONS

The levels of Pb, Cu, Cd and Zn in both the soil and different parts of *P. purpureum* from the mine dump were beyond permissible limits for soil and plant samples respectively indicating that both the soil and plant samples were contaminated. Accumulation of the heavy metals in the roots, stems and leaves of *P. purpureum* indicate that it can effectively absorb Pb, Cu, Cd and Zn from contaminated soil via roots and translocate and store them in the stems and leaves. Correlation studies indicated that the concentration of each metal in the different plant parts depend on its concentration in the respective soil sample. Synergistic interactions were observed between the quantities of the different metals in soils and different plant parts. Although *P. purpureum* growing on contaminated soil was unfit for animal consumption, it is a potential candidate for phytoremediation of soil contaminated by gold mining activities. Results obtained can provide guidance in ensuring safety for cultivation *P. purpureum* as livestock feed. It can also help in establishing safe restoration intervention for soil contaminated by gold mining activities by indicating how it could effectively remove heavy metals in soil.

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## REFERENCES

1. Ali, H., & Khan, E. (2018). Trophic transfer, bioaccumulation, and biomagnification of non-essential hazardous heavy metals and metalloids in food chains/webs - Concepts and implications for wildlife and human health. *Human and Ecological Risk Assessment: An International Journal*, 25(6):1353-1376. <https://doi:10.1080/10807039.2018.1469398>.
2. Adiloglu, S. (2017). Heavy metal removal with phytoremediation. In: Shiomi N. (Ed). *Advances in Bioremediation and Phytoremediation*, Japan: Scientific Research Publishing. <https://doi:10.5772/intechopen.70330>.
3. Arasa, R., Achuora, J., & Okello, C. (2020). Artisanal mining practices: A study of selected counties in Kenya. *International Journal in Management and Social Science*, 8(5):90-107.
4. Baker, A. J. M., Mcgrath, S. P., Reeves, R. D., & Smith, J.A.C. (2000). Ecology and physiology of a biological resource for phytoremediation of metal-polluted soils. In: Terry, N. Banuelos, G. S. 1<sup>st</sup> Ed. *Phytoremediation of Contaminated Soil and Water*, Boca Raton: CRC Press, 86 –101 p. <https://doi.org/10.1201/9780367803148>.
5. Bharti, K. R., & Sharma, R. (2021). Effect of heavy metals: An overview. *Mater Today: Proceeding*, 51:880–885. <https://doi.org/10.1016/j.matpr.2021.06.278>.
6. Chamba-Eras, I., Griffith, D.M., Kalinhoff, C., Ramírez, J., & Gázquez, M. J. (2022). Native hyperaccumulator plants with differential phytoremediation potential in an artisanal gold mine of the Ecuadorian Amazon. *Plants*, 11(9),1-14. <https://doi.org/10.3390/plants11091186>.
7. El-Amier, Y. A., El-Alfy, M. A., & Nofal M. M. (2018). Macrophytes potential for removal of heavy metals from aquatic ecosystem, Egypt: using metal accumulation index (MAI). *Plant Archives*, 18(2),2134-2144.

8. Gankhuyag, U., & Gregoire, F. (2018). Managing mining for sustainable development. UNDP, PEI, Asia Pacific. <https://www.undp.org/sites/g/files/zskgke326/files/publications/UNDP-MMFSD-HighResolution.pdf>. Accessed March 3, 2025.
9. Ghosh, M., & Singh, S. P. (2005). A review on Phytoremediation of heavy metals and utilization of its by-products. *Applied Ecology and Environmental Research*, 3(1), 1–18. [https://doi.org/10.15666/aeer/0301\\_00101](https://doi.org/10.15666/aeer/0301_00101)
10. GOK. (2016). Mining act, No. 12 of 2016, Laws of Kenya. [http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/MiningAct\\_No12of2016.pdf](http://kenyalaw.org/kl/fileadmin/pdfdownloads/Acts/MiningAct_No12of2016.pdf). Accessed April 21, 2025.
11. Haegele, T., Bunnom, T., Khumhom, S., Braeuchler, C., Liplap, P., & Arjharn, W. (2017). Expanding the farming potential of napier grass (*Pennisetum purpureum schumach.*) under low-fertile conditions. *Suranaree Journal of Science and Technology*, 24(2),137-151.
12. Hapke, H. J. (1991). Metal accumulation in the food chain and load of feed and food. In: Merian E. (Ed) *Metals and their Compounds in the Environment*. Weinheim, VCH Verges.
13. Hesami, R., Salimi, A. & Ghaderian, S. M. (2018). Lead, zinc, and cadmium uptake, accumulation, and phytoremediation by plants growing around Tang-e Douzan lead–zinc mine, Iran. *Environmental Sciences and Pollution Research*, 25,8701–8714. <https://doi.org/10.1007/s11356-017-1156-y>.
14. Hu, Y., Wang, D., Wei, L., Zhang, X., and Song, B. (2014). Bioaccumulation of heavy metals in plant leaves from Yan'an City of the Loess Plateau, China. *Ecotoxicology and Environmental Safety*, 110,82-88. <https://doi.org/10.1016/j.ecoenv.2014.08.021>.
15. ICH. (2005). ICH harmonised tripartite guideline: validation of analytical procedures: text and methodology Q2(R1). Geneva. <https://efaidnbmnnnibpcajpcgglefindmkaj/https://www.ema.europa.eu/en/documents/scientific-guideline/ich-guideline-q2r1-validation-analytical-procedures-text-methodology-step-5-first-versionen.pdf>. Accessed June 18, 2025.
16. Jahan-Nejati, S., Jowkar-Tangkarami, M., & Taei-Semiromi, J. (2021). *Cyperus rotundus*: a safe forage or hyper phytostabilizer species in copper contaminated soils. *International Journal of Phytoremediation*, 23(12),1212-1221. <https://doi.org/10.1080/15226514.2021.1888072>.
17. Juel, A. I., Dey, T. K., Akash, I. S., & Das, K. K. (2021). Heavy metals phytoremediation potential of Napier grass cultivated on tannery sludge in Bangladesh. *Journal of Engineering Science*, 12(1):35-41. <https://doi.org/10.3329/jes.v12i1.53099>.
18. Kisten, K., Gounden, D., Moodley, R., & Jonnalagadda, S. B. (2015). Elemental distribution and uptake by watercress (*Nasturtium aquaticum*) as a function of water quality. *Journal of Environmental Science and Health B*, 50,439–447. <https://doi.org/10.1080/03601234.2015.1011971>.
19. Liu, Y-J., Zhu, Y-G., & Ding, H. (2007). Lead and cadmium in leaves of deciduous trees in Beijing, China: development of a metal accumulation index (MAI). *Environmental Pollution*, 145:387-390. <https://doi.org/10.1016/j.envpol.2006.05.010>.
20. Ma, C., Ming, H., Lin, C., Naidu, R., & Bolan, N. (2016). Phytoextraction of heavy metal from tailing waste using Napier grass. *Catena*, 136,74-83. <https://doi.org/10.1016/j.catena.2015.08.001>.
21. Moore, R Z., Wilson, V., Hou, A., & Meng, G. (2015). Source of lead pollution, its influence on public health and the countermeasures. *International Journal of Health Animal Sciences and Food Safety*, 2,18–31. <https://doi.org/10.13130/2283-3927/4785>.
22. Neyole, E. M. (2005). Health Effects of Gold Mining Activities in Migori and Kakamega Districts, Western Kenya: An Environmental and Epidemiological Assessment. PhD Thesis. Eldoret, Kenya: Moi University. [https://www.researchgate.net/publication/344338553\\_health\\_effects\\_of\\_gold\\_mining\\_activities\\_in\\_migori\\_and\\_kakamega\\_districts\\_western\\_kenya\\_an\\_environmental\\_and\\_epidemiological\\_assessment](https://www.researchgate.net/publication/344338553_health_effects_of_gold_mining_activities_in_migori_and_kakamega_districts_western_kenya_an_environmental_and_epidemiological_assessment). Accessed August 2, 2025.
23. Nirola, R., Megharaj, M., Palanisami, T., Aryal, R., Venkateswarlu, K., & Naidu, R. (2015). Evaluation of metal uptake factors of native trees colonizing an abandoned copper mine – a quest for phytostabilization. *Journal of Sustainable Mining*, 14(3),115–123. <https://doi.org/10.1016/j.jsm.2015.11.001>.

24. Ogola, J. S., Mitullah, W.V., & Omulo, M. A. (2002). Impact of Gold Mining on the Environment and Human Health: A Case Study in the Migori Gold Belt, Kenya. *Environmental Geochemistry and Health*, 24:141-158. <http://dx.doi.org/10.1023/A:1014207832471>.
25. Okurut. T. O. (2002). A Pilot Study on Municipal Wastewater Treatment Using a Constructed Wetland in Uganda. PhD Thesis, The Netherlands: UNESCO-IHE, Institute for Water Education.
26. Olobatoke, R. Y., & Mathuthu, M. (2016). Heavy metal concentration in soil in the tailing dam vicinity of an old gold mine in Johannesburg, South Africa. *Canadian Journal of Soil Science*, 96:299–304. <https://doi.org/10.1139/cjss-2015-0081>.
27. Ondayo, M. A., Watts, M. J., Hamilton, E. M., Mitchell, C., Mankelow, J., & Osano, O. (2023). Artisanal gold mining in Kakamega and Vihiga counties, Kenya: potential human exposure and health risk. *Environmental Geochemistry and Health*, 45(8):1-23. Doi: 10.1007/s10653-023-01647-z.
28. Plum, L. M., Rink, L., & Haase, H. (2010). The essential toxin: impact of zinc on human health. *International Journal of Environmental Research and Public Health*, 7:1342-1365. doi:10.3390/ijerph7041342.
29. Shafie, N.A., Aris, A. Z., Zakaria, M. F., Haris, H., Yinglini, W., & Isa, N. M. (2013). Application of geoaccumulation index and enrichment factors on the assessment of heavy metal pollution in sediments. *Journal of Environmental Science and Health-Part A*, 48(2):182-190. <https://doi.org/10.1080/10934529.2012.717810>.
30. Shen, X., Chi, Y., & Xiong, K. (2019). The effect of heavy metal contamination on humans and animals in the vicinity of a zinc smelting facility. *PLoS One*, 14(10),e0207423. <https://doi.org/10.1371/journal.pone.0207423>.
31. Sheoran, V., Sheoran, A. S., & Poonia, P. (2011). Role of hyperaccumulators in phytoextraction of metals from contaminated mining sites. *Critical Reviews in Environmental Science and Technology*, 41,168–214. <https://doi.org/10.1080/10643380902718418>.
32. Shikanga, E.A. (2024). Phytoremediation Potential of *Cyperus rotundus* L. in Soils Contaminated with Potentially Toxic Elements, the Case of Abandoned Artisanal Small-Scale Gold Mines in Kenya. *International Journal of Research and Innovation in Social Science*, VIII(VIII):3507-3520. <https://dx.doi.org/10.47772/IJRISS.2024.8080260>.
33. Singh, P. (2025). An investigational analysis of Napier grass (*Pennisetum purpureum*) as a phytoremediation agent for heavy metal absorption from soil. *Scope Journal*, 5,769-778.
34. Sun, Y., Zhou, Q., & Diao, C. (2008). Effects of cadmium and arsenic on growth and metal accumulation of Cd-hyperaccumulator *Solanum nigrum* L. *Bioresource Technology*, 99(5),1103–1110. <https://doi.org/10.1016/j.biortech.2007.02.035>.
35. WHO. (1996). Permissible Limits of Heavy Metals in Soil and Plants. Geneva: World Health Organization.
36. World Gold Council. (2013). Responsible gold mining and value distribution, 2013 report. <https://www.gold.org/goldhub/research/responsible-gold-mining-and-value-distribution-2013-report>. Accessed January 15, 2025.
37. Yau, P. Y., & Murphy, R.J. (2000). Biodegraded coco peat as a Horticultural substrate, In: XXV International Horticultural Congress, Part 7: Quality of Horticultural Products. *Acta Horticulture*, 517,275-278. Doi:10.17660/ActaHortic.2000.517.33.