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Bioaccumulation of potentially toxic elements by indigenous and exotic trees growing around a copper leaching plant in Mufulira, Zambia

Charles Mulenga[1*], Darius Phiri[2], Daigard Ricardo Ortega-Rodriguez[3,4] and Martina Meincken[5]

Abstract
Potentially toxic elements (PTEs) from mining industries pollute the surrounding environment and threaten the health of communities. Worldwide, exotic and indigenous trees are being recommended for green belts to trap dust and thereby limit the dispersion of PTEs. This study compares the potential of exotic (*Eucalyptus grandis* and *E. camaldulensis*) and native (*Brachystegia longifolia*) tree species in Zambia to accumulate PTEs and evaluate their ability to biomonitor heavy metal pollution. Tree bark and leaf samples were collected from 10 trees per study species growing at the same site downwind from a copper-leaching plant. Thirty topsoil samples were collected one metre from each sampled tree trunk. Portable X-ray fluorescence was used to analyse the elemental composition and concentration of trace elements in plant and soil samples. Pollution indices were used to establish the status and degree of soil contamination, while the bioaccumulation factor determined the ability of the studied species to accumulate PTEs. Heavy metals, including Mn, Ni, Pb, Cd, Cu, Fe and Zn were detected across soil and biomass samples, with a significant variation between species and plant parts. The pollution indices established that the soil at the study site is highly contaminated with Cu. The concentration of the studied trace elements varied across species following the order *E. grandis* > *B. longifolia* > *E. camaldulensis* in both tree bark and leaves. Determined bioaccumulation factors indicated Cd, Mn and Zn accumulation abilities of all the studied species suggesting their biomonitoring and phytoremediation potential. This implies that the study species have the potential to biomonitor Cd, Mn and Zn. Furthermore, a higher concentration of Cu was detected in *B. longifolia* bark, suggesting that this tree species can be used to biomonitor Cu pollution attributed to emissions from industrial activities. This study presents new insights into improving the management of polluted environments through biomonitoring and bioaccumulation of PTEs which can guide the selection of appropriate species for greenbelts in industrial areas.

Keywords Copper, Emissions, Potentially toxic elements, Bioaccumulation factor, Biomonitoring

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*Correspondence:
Charles Mulenga
charles.mulenga@cbu.ac.zm
[1] Department of Biomaterials Science and Technology, Copperbelt University, P.O. Box 21692, Kitwe, Zambia
[2] Department of Plant and Environmental Sciences, Copperbelt University, P.O. Box 21692, Kitwe, Zambia
[3] Escola Superior de Agricultura Luiz de Queiroz, Departamento de Ciências Florestais, Universidade de São Paulo, Av. Pádua Dias 11, Piracicaba, São Paulo 13418-900, Brazil
[4] DendrOlavide-Dept. Sistemas Físicos, Químicos y Naturales, Universidad Pablo de Olavide, Crta. Utrera km. 1, Sevilla 41013, Spain
[5] Department of Forest and Wood Science, Stellenbosch University, Bag X1 Matieland, Stellenbosch 7602, South Africa

Introduction

There is an international debate on the use of exotic or native species to address the impacts of mining activities and the rehabilitation of post-mining forest ecosystems, (Ahirwal et al. 2016; Dutta and Agrawal 2003; Mondal and Singh 2022; Singh and Singh 1999).

The mineral beneficiation processes in the mining industry emit particulate matter comprising potentially toxic elements (PTEs), such as Cu, Cd, Pb and Ni (Křibek et al. 2010; Lindahl 2014; Mapani et al. 2010). Beneficiation processes may range from deposit extraction to pyrometallurgy including concentrating, refining, roasting, leaching, crushing and smelting. (Eksteen et al. 2017). Potentially toxic elements may also emanate from mining waste disposal facilities, including tailings dams, waste rock dumps, and sludge dumps (Li and Yang 2008; Mapani et al. 2010; Ngole-Jeme and Fantke 2017; Olobatoke and Mathuthu 2016). Ultimately, dust dispersion assists the mobilisation of PTEs from mining activities into the environment, contaminating water bodies and soils (Lotfi et al. 2020; Olobatoke and Mathuthu 2016).

PTEs, which are trace elements may enter the plant tissue via roots or leaves (Fernández and Brown 2013; Lee et al. 2017). They penetrate through the foliar surfaces via cuticular cracks, lenticels and stomata (Shahid et al. 2016). However, foliar uptake of these elements depends on various factors, including particle size (Schreck et al. 2012) and plant species (Bahamonde et al. 2019). Eichert et al. (2008) demonstrated that stomata restrict the adsorption of trace elements in leaves. They reported adsorption of Cu nanoparticles (43 nm) in *Vicia faba* leaves, while large sized (1.1 µm) particles could not penetrate. Similarly, Bahamonde et al. (2019) observed significant variations in the rate of foliar resorption in Cu, Fe, Mn, Al, Ti and B in *Nothofagus pumilio* and *N. antarctica*. On the other hand, trace elements are absorbed by the roots as ions in the soil. They are then taken up by root hairs and translocated through apoplastic and symplastic pathways, depositing them into the xylem tissue for upward transportation (Luo et al. 2016) to different plant parts (Page and Feller 2015). However, the extent and rate of translocation depends on several factors, including plant species and element speciation (Adriano 2001; Roberts et al. 2005).

The accumulation of PTEs has been reported in woody plants growing near mining areas in Mufulira and other towns of Zambia. Mulenga et al. (2022a) reported elevated levels of Cu, Zn, Fe and Mn in *Brachystegia longifolia* Benth naturally growing near mining activities in Mufulira. Křibek et al. (2019) and Mihaljevič et al. (2018) observed a significant accumulation of Zn and Cu in tree growth rings of *Pinus oocarpa* and *P. Kesiya* attributed to mining activities in Kabwe and Kitwe. Furthermore, Ncube and Phiri (2015) recorded elevated Cd, Pb and Cr concentrations in *Eucalyptus closiana, P. Kesiya and P. oocarpa* and *P. kesiya* harvested from industrial areas in Ndola and Kitwe. However, these studies are confined to exotic species and the comparative uptake and accumulation of PTEs by indigenous and exotic tree species is not well understood.

Exotic trees i.e., *Eucalyptus grandis* W. Hill and *E. camaldulensis* Dehnh have been planted around a copper-leaching plant to serve as live fencing at a mine in Mufulira, Zambia. Native species to the Miombo woodlands are also naturally growing around the leaching plant. The trees on this site are being used as a greenbelt; trapping dust and possibly limiting the dispersion of PTEs across the surrounding areas, including a residential site within 1 km radius. This community is comprised of housing units, education and health facilities whose occupants could be affected by PTEs emanating from the leaching plant. However, there is a lack of comparative field-based scientific evidence on the potential and thereby, the effectiveness of these tree species in accumulating PTEs.

It is widely accepted that, the ability of plants to absorb and accumulate PTEs depends on many factors including plant species. This study compared the ability of *E. grandis*, *E. camaldulensis* and *B. longifolia* tree species to accumulate PTEs and to biomonitor heavy metal pollution.

A characteristic species of the Miombo woodlands, *B. longifolia*, is of high commercial value and widely distributed in Zambia, Zimbabwe, Tanzania, Malawi, Mozambique, Angola and the Democratic Republic of Congo (Jimu et al. 2017). *E. grandis* and *E. camaldulensis* are non-native tree species introduced in urban areas decades ago, mainly for timber production. Timber from all the three studied species is used for construction, furniture manufacturing and bioenergy production.

Materials and methods

Study area description

Mufulira, the study site, is located 43 km from Kitwe in the Copperbelt Province of Zambia (Fig. 1). This mining town is located at 12°31′ 59” S, and 28° 13′ 55” E and has one of the largest underground mines in Zambia. The average wind speed is 2.4 m/s and the main wind direction is towards the west (Mulenga et al. 2022a). This defines the areas to the west and east of the copper leaching plant as downwind and upwind, respectively.

Axenhamn & Simukanga (2005), Chifungula (2014) and Mulenga at al. 2022a observed high levels of dust emissions from the copper mine dispersed across the surrounding forests. Furthermore, Mulenga et al. (2022a) observed that areas up to 12 km downwind and 7 km upwind are contaminated with Cu emanating from mining activities.

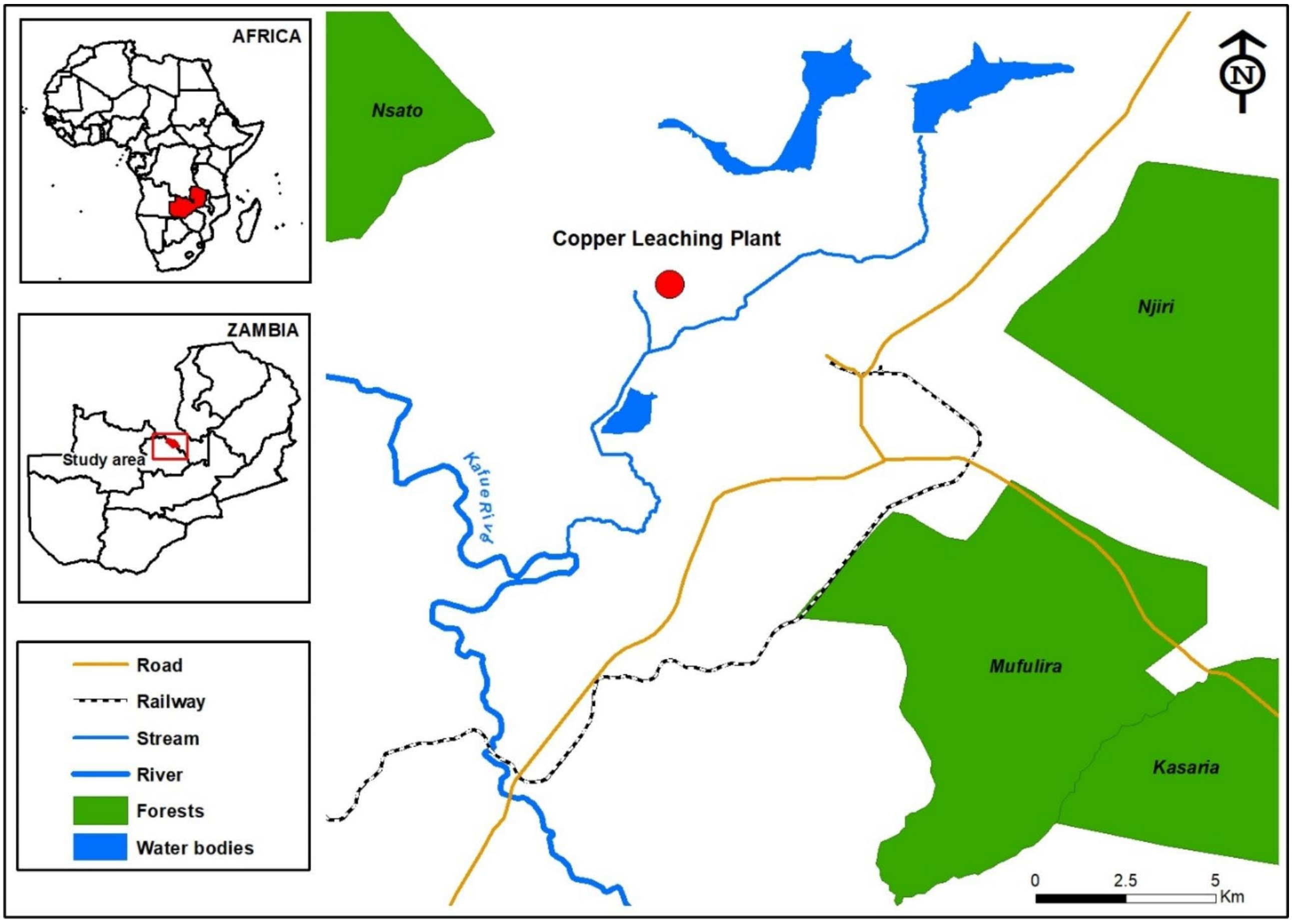

Fig. 1 The location of the copper leaching plant in Mufulira

The sampling strategy of the study

Tree bark was extracted at breast height (1.2 m) and topmost leaves harvested to constitute biomass samples. Ten (10) samples were extracted from 10 trees with a DBH ranging between 12 and 16 cm (*B. longifolia*), as well as 14 and 18 cm (*E. grandis* and *E. camaldulensis*). DBH capping was done to ensure that biomass samples are collected from trees within a similar age group and minimise the age influence on the generated data within and across tree species (Mulenga et al. 2022a). In addition, surface soil was collected at 10 cm depth, one metre away from each sampled standing tree trunk, facing the copper leaching plant (Dumčius 2016; Greece 2009; Zinkutė et al. 2006). In total, 30 soil samples were collected and analysed. All the samples were collected from the same site, about 500 m downwind of the copper leaching plant.

Preparation and analysis of samples

The collected tree bark and leaves were washed under running deionised water and oven-dried at 105±5 °C to constant moisture content (Tokalioǧlu et al. 2001; Yang et al. 2013). Oven-dried bark and leaves were ashed at 575 °C for 3 h (Buchmann et al. 2000; Enders and Lehmann 2012; Ge et al. 2008; Shen et al. 2015; Väisänen et al. 2008). Soil samples were pulverised by hand, sieved by vibration and oven-dried at 105±5 °C to constant moisture content (Ichikawa and Nakamura 2016; Nuchdang et al. 2018; Tavares et al. 2019). Light pulverisation was performed to avoid crushing or milling stones, which could affect the soils' chemical composition and then mechanically sieved through a 150 µm sieve, obtaining the fine particle sizes suitable for elemental analysis (Demir et al. 2008; Ichikawa and Nakamura 2016; Mzyk et al. 2002; Yagura et al. 2019).

A Thermo Niton XL3t GOLDD+ (pXRF-portable X-ray fluorescence) was used to analyse the composition and concentration of PTEs in all samples. Portable X-ray fluorescence analysis offers a quick and reliable alternative or complement to traditional techniques (ICP-AES, ICP-MS, ICP-OES and AAS) producing relative concentrations (counts of fluorescent photons per second, cps) and allowing for extensive, inexpensive and faster analysis regimes (Al Maliki et al. 2017; Congiu et al. 2013; Marcos et al. 2011; Rouillon and Taylor 2016). Furthermore, this method has been implemented in different studies evaluating soil (Congiu et al. 2013; Janotková et al. 2013; Rizvi et al. 2020; Rouillon and Taylor 2016) and plant (Chojnacka et al. 2018; Elzain et al. 2016; Marguí et al. 2005; Mulenga et al. 2022a; Roquette et al. 2023) trace element contamination. Soil pH was determined through potassium chloride (KCl) on air-dried soil (Mulenga et al. 2022a).

Analysis of soil pollution status and degree of soil contamination

The degree and status of soil contamination were analysed through the Enrichment factor (EF) and Geoaccumulation index (GI). These indices are suitable to assess anthropogenic-induced soil pollution (Kowalska et al. 2018). The GI and EF pollution indices were calculated using Eq. 1 and Eq. 2, respectively (Sutherland 2000):

$$GI = log_2\left[\frac{SampleM_c}{1.5 * GB}\right] [1]$$

$$EF = \left\{\frac{Sample\left[\frac{M_c}{N_e}\right]}{WASV\left[\frac{M_c}{N_e}\right]}\right\} [2]$$

Where M_c: total concentration of trace element in the soil sample, GB: World average shale values (WASV) or trace element background value and Ne: normalization element from PTEs with low soil occurrence variability, e.g. Al, Ca, Fe, Mn, Ti or Si (Mazurek et al. 2017). The factor 1.5 in the calculation of GI takes into account fluctuations in geochemical background values relating to natural weathering or lithogenic effects (Abdullah et al. 2020; Kowalska et al. 2018; Nowrouzi and Pourkhabbaz 2015).

The WASV (Onjefu et al. 2020) were used in this study for lack of pre-industrial geochemical background values in the study area (Mulenga 2022). WASV values of 45 mg/kg (Cu), 47,200 mg/kg (Fe), 850 mg/kg (Mn), 68 mg/kg (Ni), 20 mg/kg (Pb), 94 mg/kg (Zn), 5700 mg/kg (Ti) and 16 mg/kg (Cd) were used to calculate GI and EF. These values have been used and recommended in various studies (Kowalska et al. 2018; Mulenga et al. 2022a; Nowrouzi and Pourkhabbaz 2015; Onjefu et al. 2020) for soil pollution assessments in territories lacking site-specific geochemical references, including mining environments. Titanium was used as normalization element because of its low occurrence variability across the soil samples.

The classification and interpretation of the pollution indices obtained from Eq. 1 and Eq. 2 are outlined in Table 1. EF values ranging between 0.5 and 1.5 are caused by variations in metal concentration in the soil due to natural weathering. If EF is larger than 1.5 the fluctuation of metal content in the soil can be attributed to anthropogenic activities (Abdullah et al. 2020; Kowalska et al. 2018; Nowrouzi and Pourkhabbaz 2015).

Table 1 [1]Soil contamination criteria based on GI and EF.

Enrichment factor		Geoaccumulation index	
Classification	Degree of soil enrichment	Classification	Degree of soil contamination
0 < 2	Deficient	GI < 0	Unpolluted
2 < EF < 5	Moderate	1 ≤ GI < 2	Moderately polluted
5 < EF < 20	Significant	3 ≤ GI < 4	Strongly polluted
20 < EF < 40	Very significant	4 ≤ GI < 5	Strong to very strong polluted
EF > 40	Extremely significant	GI ≥ 5	Very strongly polluted

Analysis of potentially toxic element bioaccumulation in trees

The bioaccumulation factor (BAF) was used to determine the potential of *E. grandis*, *E. camaldulensis* and *B. longifolia* to accumulate PTEs. BAF is a measure of the ability of a plant species to accumulate specific trace elements in its tissues and one of the factors used in identifying species for phytoremediation strategies and biomonitoring. It is calculated as a ratio between the elemental composition in plant shoots or leaves and the respective total element concentration in the soil or growth medium, Eq. 3 (Molnár et al. 2020).

$$BAF = C_p/C_{so} [3]$$

Where C_p: element content in leaves or shoots and C_{so}: total content of an element in the growth medium or soil. Plants with element BAF values larger than one are regarded as accumulators, capable of compartmentalizing specified trace elements in the their tissues (Cruzado-Tafur et al. 2021).

Statistical data analysis

Analysis of variance (ANOVA) was conducted to establish variations on the concentration of PTEs in biomass samples of the studied species. Significant variations are reported at $p<0.05$. The graphs and statistics were produced using a statistical package, R (R Core Team, 2022).

Results and discussion

Degree and source of soil contamination

This study evaluated PTEs that were detected across the three sample types. A total number of seven PTEs (Mn, Ni, Pb, Cd, Cu, Fe and Zn) were detected across the sample types. There was a significant variation on the concentration of different PTEs in the soil. The average concentration accounted for 30,388 mg/kg (Fe), 2912 mg/

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[1] Adapted from Abdullah et al. (2020) and Onjefu et al. (2020).

kg (Cu), 701 mg/kg (Mn), 67 mg/kg (Ni), 57 mg/kg (Zn), 26 mg/kg (Cd) and 25 mg/kg (Pb).

The soil pollution assessments carried out indicates that the study site is mostly polluted with Cu (Fig. 2). The geoaccumulation index, which compares the current concentration of trace elements to pre-industrial levels in the soil shows very strong soil contamination (GI ≥ 5) around the copper leaching plant. Furthermore, the EF pollution index, which measures both soil pollution status and possible source of enrichment confirmed significant Cu pollution (EF > 20) around the leaching plant, driven by anthropogenic activities (EF > 1.5).

These results confirm the dispersion of dust from the copper leaching plant in Mufulira and demonstrate the impact of anthropogenic activities, including mining on forest soil in the surrounding landscape (Li and Yang 2008; Mapani et al. 2010; Ngole-Jeme and Fantke 2017; Olobatoke and Mathuthu 2016). Similar results have been reported in different mining towns in Zambia and other mining countries (Ettler et al. 2022; Ikenaka et al. 2014; Kříbek et al. 2019; Matakala et al. 2023; Mihaljevič et al. 2018; Van Der Ent et al. 2020). In Zambia, Cu and Co soil contamination was observed in Luanshya (Ettler et al. 2022), Pb-Zn soil pollution in Kabwe (Kříbek et al. 2019) and Cu soil enrichment in Kitwe (Mihaljevič et al. 2018), all attributed to emission dispersion from mining activities.

The soil pH recorded from all the 30 soil samples on the study site ranged from 3.45 to 4.36, confirming earlier studies in the area noting that forest soil in Mufulira and the surrounding is strongly acidic (Mulenga et al. 2022a; Tsuji et al. 2005).

Concentration of potentially toxic elements in plants

The concentration of PTEs varied significantly based on tree species and plant organ (Fig. 3). Mn, Zn and Pb concentration was higher in leaves than tree bark, for all studied tree species. On the other hand, Fe, Ni, Cd and Cu varied significantly among tree species and plant organs. In *B. longifolia*, Cu, Cd and Ni were significantly higher in tree bark than leaves. A similar trend was observed in *E. grandis* for Cu, Fe and Ni.

The observed heavy metal concentration behaviour especially in *B. longifolia* can be attributed to Cu adsorption through the stem because the bark of this tree species is grooved with deep vertical fissures (Storrs 1995). Furthermore, Storrs (1995) noted that the bark is ridged in long strips, which crack horizontally resulting in square flakes and the grooves on the stem look like claw marks. On the other hand, the bark of *E. camaldulensis*

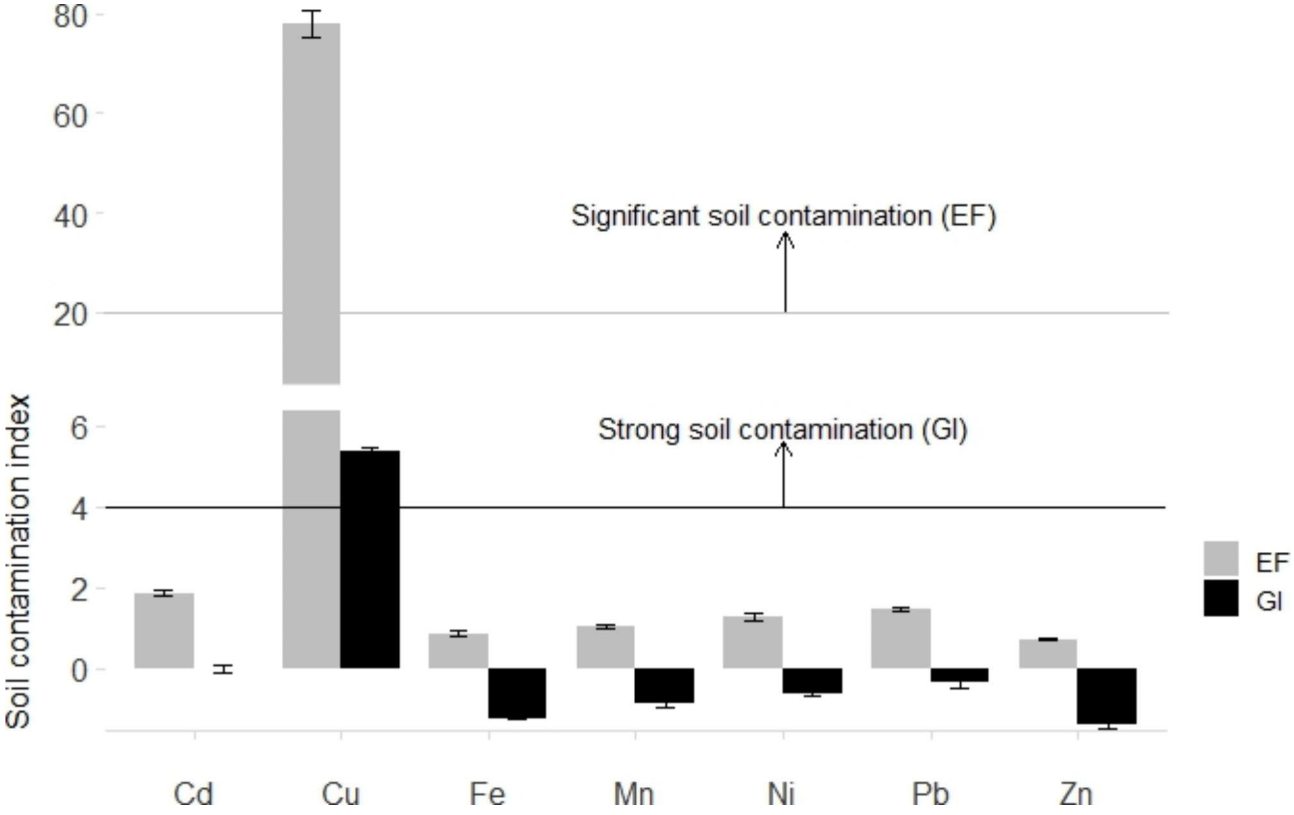

Fig. 2 Status and degree of soil contamination based on GI and EF of each studied PTEs, n = 10. The error bars represent the standard error of the mean

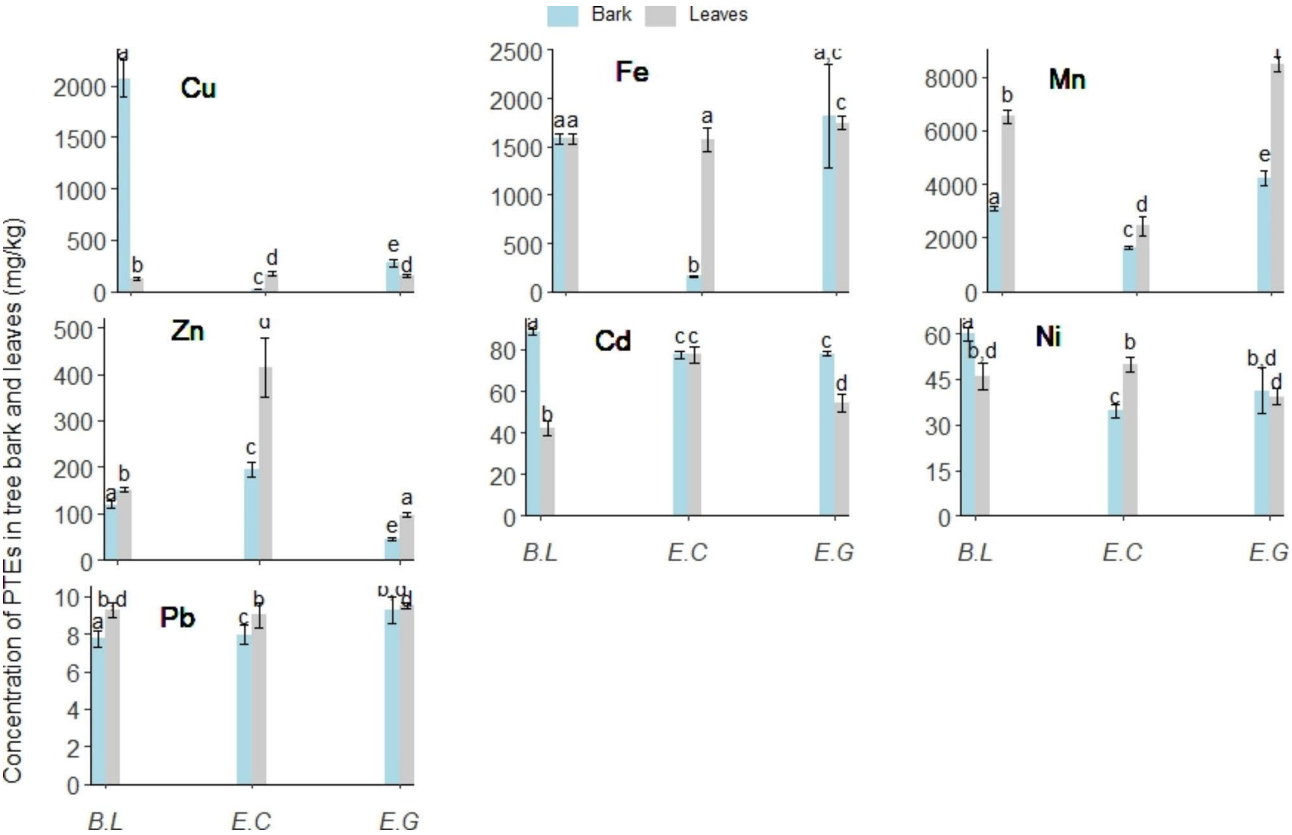

Fig. 3 Concentration of PTEs in tree bark and leaves, n = 10. The different letters indicate mean significant differences at 5% of significance between species. B.L: *B. longifolia*, E.C: *E. camaldulensis* and E.G: *E. grandis*. The error bars represent the standard error of the mean

is smooth with rough and loose slabs at the base (Ali and Usman 2022; Sani et al. 2014).

The enrichment factor of over 1.5 for Cu in Fig. 2 shows that Cu soil contamination on this study site is instigated by anthropogenic activities. Since copper-leaching is the only anthropogenic activity at the study site, Cu pollution on this site can be attributed to the dispersion of mineral enriched dust from the copper mine. Consequently, more mineral particles are trapped and adsorbed into the bark from the atmosphere by highly fissured bark.

Similar results have been reported in other studies where tree bark passively accumulated PTEs from the atmosphere and served as an active transport surface, exchanging these elements longitudinally and laterally (Dogan et al. 2014; Luo et al. 2016; Page et al. 2006; Ponette-González 2021; Rodríguez et al. 2018). Furthermore, the effectiveness of tree bark in trace element adsorption and the potential of biomonitoring atmospheric pollution is strongly attributed to its surface morphology, or fissures and lenticel size and distribution (Alatou and Sahli 2019; Caldana et al. 2023; Catinon et al. 2009; Chrabąszcz and Mróz 2017; Drava et al. 2017; Guéguen et al. 2012; Olajire and Ayodele 2003; Reimann et al. 2007). These results demonstrate that *B. longifolia* bark can be used for biomonitoring atmospheric Cu pollution. It further suggests that sampling tree bark rather than leaves offers a better sampling option in assessing the concentration of Cu in *B. longifolia* and possibly other tree species, attributed to dust emissions.

It is clearly demonstrated in Fig. 3 that the native *B. longifolia* leaves recorded more Zn and Mn than *E. camaldulensis* and *E. grandis*, respectively. The concentration of Cd, Ni and Cu were significantly higher in *B. longifolia* tree bark than in leaves. The ability of *B. longifolia* to absorb more Mn and Zn has previously been attributed to adaptation of this tree species to its native acidic Miombo woodlands (Mulenga et al. 2022b). Comparable results have been reported in *Pseudotsuga menziesii* (Radwan et al. 1979), as well as *Populus trochocarpa*, *Tsuga heterophylla*, *P. Menziesii* and *P. Nigra* (Zasoski et al. 1990), grown in acidic growth medium. However, the concentration of PTEs in Fig. 3 shows elevated levels of Cu, Mn and Cd in all species and Zn in *E. camaldulensis* and *B. longifolia.* These concentration levels could be toxic and impact on tree growth and forest productivity. Critical toxicity varies depending on plant species, but average limits are >10 mg/kg (Cd), > 120 mg/kg (Zn), > 25 mg/kg (Cu) and >200 mg mg/kg (Mn) for non-hyperaccumulators (Emamverdian et al. 2015; Krämer 2010; Sharma et al. 2016).

Bioaccumulation of potentially toxic elements in tree bark and leaves

The bioaccumulation factor is a measure of the ability of plant species to accumulate specific trace elements in plants parts. Figure 4 shows that the studied species can take up and compartmentalize selected trace elements in the bark and leaf tissues in varying quantities. The bioaccumulated elements include Cd, Mn, and Zn. The results show that Mn and Zn accumulates more in the leaf than in tree bark tissue for all studied species. Conversely, Cd accumulates more in tree bark than in leaves.

Furthermore, Fig. 4 demonstrates significant differences in the bioaccumulation of trace elements across tree species and plant parts. *E. grandis* accumulated the highest levels of Cd, Mn and Zn compared to *E. camaldulensis* and *B. longifolia*. The average bioaccumulation levels in *E. grandis* followed the order Mn > Cd > Zn for both leaves and tree bark. However, the bioaccumulation order of PTEs in *E. camaldulensis* was Zn > Mn > Cd (leaves) and Zn > Cd > Mn (bark). Finally, variations in the bioaccumulation patterns of PTEs in *B. longifolia* followed the order Mn > Zn > Cd (leaves) and Mn > Cd > Zn (bark).

These results confirm an earlier study that demonstrated that *B. longifolia* can accumulate Mn and Zn (Mulenga et al. 2022a). Furthermore, the results demonstrates the potential of the studied species in phytoremediation, restoring Mn, Cd and Zn contaminated landscapes. Other studies have also observed several woody plants accumulating selected PTEs including Cd (Amirahmadi et al. 2020; Chaplygin et al. 2020), Mn (Fernando et al. 2006; Millaleo et al. 2010; Yang et al. 2008) and Zn (Chaplygin et al. 2020; Shi et al. 2011), attributed to the acidic growth medium (Shaari et al. 2024), which instigates the transformation from insoluble to plant available forms of these elements (Li et al. 2014). However, the ability of plants to accumulate PTEs depend on many factors, including species and trace elements.

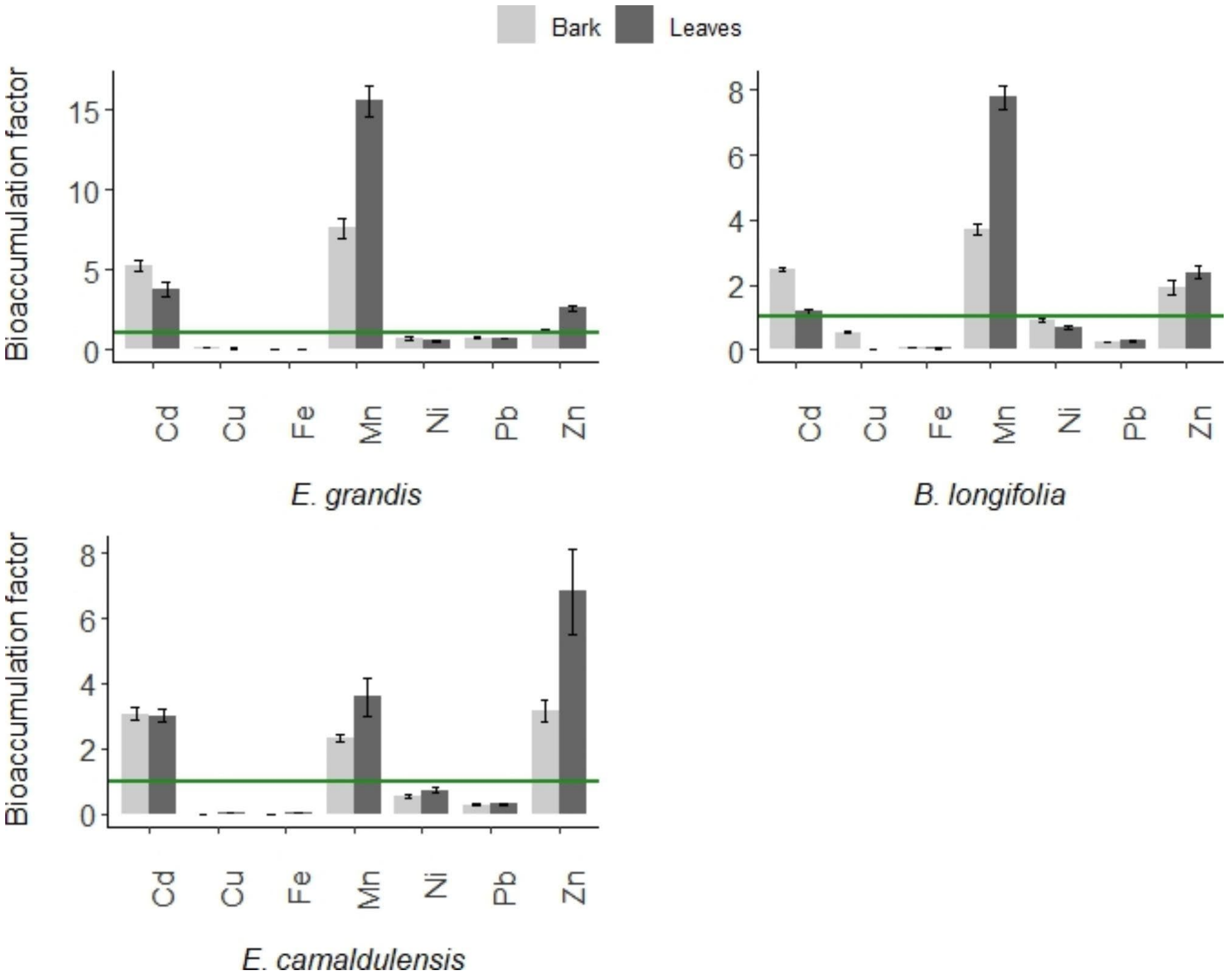

Fig. 4 Bioaccumulation of PTEs in plants, n = 10. The horizontal line shows the bioaccumulation limit. PTEs with values exceeding this line can accumulate in the respective tree species. The error bars represent the standard error of the mean

Matakala et al. (2023) studied the ability of native woody species naturally growing on tailing dams to accumulate trace elements in leaves and roots. They observed that *Annona senegalensis*, *Parinaric curatellifolia* and *Dombeya rutundilifolia* could accumulate Ni, Co, Cu, Mo and Cr well. Conversely, these species could not accumulate Ba, B, Zn and Mn. Comparable results have been reported in several other studies (Collin et al. 2022; El-Khatib et al. 2020; Pietrelli et al. 2022; Robin et al. 2022; Thanh-Nho et al. 2019; Uddin et al. 2021).

The fraction of PTEs absorbed by root cells and translocated throughout the plant depends on the plant's uptake characteristics, namely the selectivity/exclusion or accumulation (White 2012). Therefore, the inability of the studied species to accumulate Cu, Ni, Pb and Fe could be attributed to selectivity/exclusion mechanisms (Atkinson and Guerinot 2010; Fernando and Lynch 2015; Rietra et al. 2017; Schulz 2010; Sharma et al. 2016).

In an extensive review, Mulenga et al. (2020) pointed out that different trace elements have varying effects on plants depending on the quantities absorbed and their subsequent role in biochemical and physiological processes in plant tissues. Notably, only a few studies have gone further to establish the effect of these elements on tree growth and utility properties to assess the productivity of forests within the reach of emissions from mining activities. Understanding the impact of mining activities on forest productivity can help to formulate strategies aimed at addressing sustainable mining challenges.

Absorption and translocation of trace elements in plants

The uptake of trace element ions from the soil solution into plant roots is facilitated by proteins referred to as transporters. The main transporters include the family members of heavy metal ATPases (adenosine triphosphate) (HMA), zinc-iron permease (ZIP) and natural resistance-associated macrophage protein (NRAMP) (Shi et al. 2019). These are localized in different parts of the root cell compartments. Each family member of these transporters participates in the uptake and translocation of different trace elements depending on their affinity (Milner et al. 2014). Studies on *Nocatee caerulescens* and *Arabidopsis thaliana* show that AtZIP2 absorbs and translocates Mn^{2+}/Zn^{2+} into the root cells. Furthermore, NcZNT1, a homolog of AtZIP4 absorbs and transport Zn^{2+} and Cd^{2+}, while IRT1 is involved in the uptake of Cd^{2+}, Zn^{2+}, Fe^{2+} and Fe^{3+} (Lin et al. 2016; Lombi et al. 2002). All these transporters are localized in the plasma membrane.

NRAMP family members specialize in absorbing bivalent ions into the root stellar cells, while HMAs translocate both divalent and monovalent ions throughout the plants (Milner et al. 2014). HMAs (AtHMA1, AtHMA2 and AtHMA4) facilitates the translocation ions into shoots from roots (Cun et al. 2014).

Other trace element ions form complexes with phytochelatins (Kozhevnikova et al. 2014). These complexes are then absorbed by root cells through oligopeptide transporters and ATP-binding cassette (Richau et al. 2009). However, Luo et al. (2016) argued that the mechanisms governing the uptake and translocation of potentially toxic element ions in woody plants is not well established. They suggested that the inflow of toxic elements into woody roots is greater than herbaceous roots. This position was earlier supported by He et al. (2011) observed a 100 times lower Cd^{2+} inflow into the roots of herbaceous *Triticum aestivum* than woody *Populus tremula* and *Populus alba.* However, it is widely accepted that the uptake and translocation of trace element ions in plants depends on many factors, including transporters and species.

The selective ability of transporters in the uptake of trace element ions from the soil solution into the root cell and their subsequent translocation throughout the plant gives rise to significant variations in the concentration of these elements in plant tissues. Consequently, elements with a higher distribution network are absorbed and translocated in large quantities from the growth medium, possibly explaining the variations in the bioaccumulation or hyperaccumulation potential of different plant species. It is demonstrated in Fig. 4 that despite Cu and Fe recording higher concentration in the soil, the concentration of these elements in the tissues of studied tree species was lower than the growth medium. Future studies should establish and compare the expression of these transporters across the studied species, and possibly other tree species with phytoremediation potential. This would help fast-track the identification of accumulators and hyperaccumulators of PTEs based on transporters, for the benefit phytoremediation programmes.

Conclusions

The aim of this study was to compare the potential of the three tree species to accumulate PTEs and evaluated the ability of the tree species in biomonitoring heavy metal pollution. Pollution indices (EF and GI) were employed on soil samples to establish the status and degree of contamination, while the bioaccumulation factor was used for biomass samples (bark and leaves) from 10 trees to assess bioaccumulation and biomonitoring potential. The study detected seven PTEs across soil and biomass samples, which included Mn, Ni, Pb, Cd, Cu, Fe and Zn. The pollution indices established that the soil on the study site is highly polluted with Cu, confirming the dispersion of dust from the copper leaching plant and demonstrated the serious impact of mining related anthropogenic causes on the study site. Of the three tree species, *E. grandis* had the highest accumulation of heavy metals followed by *B. longifolia* and *E. camaldulensis;* however, the general concentration varies based on specific plant parts (bark or leaves). Furthermore, the study showed that the tree species can accumulate selective trace elements in the bark and leaves at varying quantities, with elements such as Cd, Mn, and Zn being common. It also demonstrated that *B. longifolia* bark can be used to biomonitor Cu dust emissions attributed to industrial activities. This study delivers new insights in improving the management of polluted environment through biomonitoring and phytoremediation as the findings from this study can guide policy on species selection when establishing greenbelts in mining and other industrial areas. Specifically, the study shows that native tree species naturally growing in polluted landscapes have the potential in biomonitoring metal pollution and are also possible candidates in phytoremediation strategies.

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Author contributions

CM: Study conceptualization, sample collection and data analysis. CM, DP, OR and MM: Study design, results interpretation and manuscript drafting. MM: Mobilised resources and supervised the study. MM: Manuscript editing. All authors read and approved the final manuscript.

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Data availability

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate

Not applicable.

Consent for publication

Not applicable.

Competing interests

The authors declare that they have no competing interests.

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