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Comparative accumulation and root-to-leaf partitioning of arsenic, lead, cadmium and mercury in indigenous and exotic tree species on a rehabilitated gold-mine landscape at Ayanfuri, Ghana

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Article

Keywords: Phytostabilisation, Translocation factor, Potentially toxic elements, Waste dump revegetation, Tectona grandis, West Africa

Posted Date: October 30th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11321636/v1

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Additional Declarations: No competing interests reported.

Abstract

Trees are widely planted on rehabilitated gold-mine waste to stabilise degraded land, but species are usually chosen for growth performance, with little attention to how they take up and distribute potentially toxic elements (PTEs). We screened arsenic (As), lead (Pb), cadmium (Cd) and mercury (Hg) in the roots and leaves of 19 trees of 17 species, five indigenous to West Africa and twelve introduced, growing on three reclaimed waste dumps and in two reference forests at the Edikan concession, Ayanfuri, Ghana. On a whole-plant basis, indigenous trees had higher median concentrations than exotic trees of As (0.82 versus 0.22 mg kg^{-1}), Pb (0.61 versus 0.25 mg kg^{-1}) and Cd (0.52 versus 0.27 mg kg^{-1}) (Mann–Whitney U test; p = 0.022, 0.018 and 0.009; q = 0.029 for each after false discovery rate adjustment). Hg did not differ between the groups (p = 0.106). Median leaf-to-root translocation factors were 0.95–0.99 for all four elements, so leaf concentrations were close to, and in most trees slightly below, root concentrations. *Ceiba pentandra* had the highest As and Pb, *Terminalia superba* and *Triplochiton scleroxylon* the highest Cd, and the exotic *Tectona grandis* the highest Hg, with about twice as much in its leaves as in its roots. Indigenous species thus accumulated more As, Pb and Cd without concentrating them in foliage, making them candidates for phytostabilisation trials. The study is exploratory: no soil was analysed, so soil-to-plant transfer factors could not be calculated, and most species are represented by one tree.

1 Introduction

Gold mining leaves behind large volumes of waste rock and tailings, and closure and rehabilitation do not remove the metal-bearing material they contain. A common rehabilitation strategy in the humid tropics is to establish tree cover on decommissioned dumps: the canopy controls erosion, restores organic inputs and returns the land to a vegetated state (Mendez & Maier, 2008; Sheoran et al., 2011). Where the objective goes beyond erosion control to reducing the mobility of residual contaminants, the relevant process is phytostabilisation, the immobilisation of potentially toxic elements (PTEs) in the root zone and their retention below ground rather than their extraction into harvestable biomass (Bolan et al., 2011). Whether a species suits that role depends on two properties: how much of each element it accumulates, and where in the plant it stores what it takes up.

Planting stock for rehabilitated mine land in Ghana is often chosen for growth rate, survival and canopy performance, and fast-growing exotics such as *Acacia* and *Leucaena* are widely planted for those reasons. Indigenous species are given priority less often, although native plants are argued to be better matched to local soil conditions and better able to tolerate them (Boi et al., 2023; Kahangwa et al., 2021). Native plants on a former gold mine in Ghana have been screened for phytoremediation potential (Petelka et al., 2019), but whether indigenous and exotic trees differ in PTE accumulation and internal partitioning when they grow on the same West African mine landscape has rarely been tested.

Two design features determine what such a test can conclude. The first is the tissue analysed. Because phytostabilisation depends on root retention, the informative measurement is the comparison between

root and leaf concentrations within the same individual, expressed as a translocation factor (leaf-to-root ratio). The second is the reference against which accumulation is judged. For non-edible tree tissue the appropriate benchmarks are the background and phytotoxic ranges reported for plants (Kabata-Pendias, 2011), not the food-safety limits that apply to edible crops.

This study screens four PTEs of concern in Ghanaian gold-mining areas (As, Pb, Cd and Hg) in the roots and leaves of tree species growing on rehabilitated waste dumps and in adjacent reference forest at the Edikan concession, Ayanfuri. We are not aware of an earlier study from West Africa that compares indigenous and exotic trees on the same rehabilitated gold-mine landscape using paired root and leaf measurements of these four elements. The objectives were (i) to quantify As, Pb, Cd and Hg in root and leaf tissue of the tree species present; (ii) to compare accumulation between indigenous and exotic species; and (iii) to characterise root-to-leaf partitioning as an indicator of phytostabilisation potential. The study is an exploratory screening exercise. It includes no soil sampling, so soil-to-plant transfer factors are not reported, and most species are represented by a single tree, so its conclusions are provisional and intended to generate hypotheses.

2 Materials and methods

2.1 Study area and sites

The study was carried out at the Edikan Gold Mine concession operated by Perseus Mining (Ghana) Limited, near Ayanfuri in the Upper Denkyira West District of the Central Region of Ghana. The area has a semi-deciduous forest climate with a bimodal rainfall regime (annual rainfall of about 1,300 mm to more than 2,000 mm), a mean annual temperature of about 26°C, and predominantly acidic, iron-rich ochrosol (Ferralsol) soils (Amponsah et al., 2015). Sampling was conducted at five sites: three reclaimed waste dumps at different post-rehabilitation ages, Fobinso (approximately 10 years), Abenabena (approximately 12 years) and Fetish (approximately 14 years), and two undisturbed forest sites serving as ecological references, the Maxam Junction natural forest and the IT Tower Line secondary forest (Fig. 1; Table 1). The reference forests have no history of mine-waste deposition and represent the regional vegetation against which the rehabilitated dumps are compared.

Table 1
Description of the five sampling sites

Site	Type	Age (yr)[a]	Description
Fobinso	Reclaimed waste dump	~ 10	Former waste-rock dump on sheared, gold-mineralised sediment; rehabilitated and revegetated
Abenabena	Reclaimed waste dump	~ 12	Former domestic-waste landfill, rehabilitated and restored to vegetated cover
Fetish	Reclaimed waste dump	~ 14	Dump active for about 10 years, then decommissioned and rehabilitated; now supports mixed indigenous and exotic trees
Maxam Junction	Reference forest	~ 20	Undisturbed semi-deciduous natural forest that developed without significant human intervention
IT Tower Line	Reference forest	~ 20	Undisturbed secondary forest on hilly terrain; no mine-waste history

[a] Ages are approximate, from site rehabilitation records

2.2 Species sampled and experimental unit

Seventeen tree species were sampled: five indigenous to West Africa and twelve introduced (exotic). Species were assigned to the indigenous or exotic group from their documented native range, not from their presence at the site. The indigenous group comprised *Ceiba pentandra*, *Ficus exasperata*, *Triplochiton scleroxylon*, *Terminalia superba* and *Entandrophragma angolense*. The exotic group comprised *Acacia mangium*, *Acacia auriculiformis*, *Acacia siamea*, *Leucaena leucocephala*, *Gliricidia sepium*, *Tectona grandis*, *Theobroma cacao*, *Persea americana*, *Morinda citrifolia*, *Solanum torvum*, *Claoxylon indicum* and *Canarium album*.

The experimental unit is the individual tree, and 19 trees were sampled in total (Table 2). Root and leaf material were collected from each tree and analysed as two separate tissues, giving 38 tissue measurements (19 root, 19 leaf). Root and leaf values from the same tree are paired tissues of one individual, not independent biological replicates, and are used to characterise within-tree partitioning (Section 2.4). Twelve of the 19 trees grew on reclaimed dumps and seven in the reference forests. Because most species occur at a single site and are represented by one tree, the design supports a description of the species present and a group-level (indigenous versus exotic) comparison, but not a statistically powered comparison among individual species (Section 2.4).

Table 2
Tree species sampled, origin group and site of collection. Each row is one tree analysed as root and leaf tissue (n = 19 trees; 38 tissue measurements)

Species	Origin	Site (type)
Ceiba pentandra	Indigenous	Fetish (reclaimed dump)
Ficus exasperata	Indigenous	Fetish (reclaimed dump)
Leucaena leucocephala	Exotic	Fetish (reclaimed dump)
Acacia mangium	Exotic	Fetish (reclaimed dump)
Claoxylon indicum	Exotic	Maxam Junction (reference forest)
Theobroma cacao	Exotic	Maxam Junction (reference forest)
Canarium album	Exotic	Maxam Junction (reference forest)
Solanum torvum	Exotic	Maxam Junction (reference forest)
Ceiba pentandra	Indigenous	Fobinso (reclaimed dump)
Morinda citrifolia	Exotic	Fobinso (reclaimed dump)
Leucaena leucocephala	Exotic	Fobinso (reclaimed dump)
Gliricidia sepium	Exotic	Fobinso (reclaimed dump)
Persea americana	Exotic	Abenabena (reclaimed dump)
Triplochiton scleroxylon	Indigenous	Abenabena (reclaimed dump)
Acacia auriculiformis	Exotic	Abenabena (reclaimed dump)
Tectona grandis	Exotic	Abenabena (reclaimed dump)
Terminalia superba	Indigenous	IT Tower Line (reference forest)
Entandrophragma angolense	Indigenous	IT Tower Line (reference forest)
Acacia siamea	Exotic	IT Tower Line (reference forest)

Indigenous species, n = 6 trees (*Ceiba pentandra* sampled at two dumps); exotic species, n = 13 trees (*Leucaena leucocephala* sampled at two dumps). All other species were sampled once

2.3 Sample collection and analysis

At each site, trees of the target species were sampled from demarcated 30 m × 30 m plots in June 2025. Root and leaf material were collected from each selected tree, labelled, sealed and transported to the laboratory, where they were washed with deionised water to remove adhering soil and surface dust, oven-dried, homogenised and digested in HNO_3 by closed-vessel microwave digestion before analysis. Concentrations of As, Pb, Cd and Hg were determined by inductively coupled plasma mass spectrometry (ICP-MS) and are reported in mg kg^{-1} dry weight.

Two constraints on the analytical record must be stated. First, element-specific instrument parameters, calibration ranges, limits of detection and quantification, certified reference material recoveries and replicate precision were not available to the authors for reporting, and the results are taken as reported without accompanying quality-control data. Second, closed-vessel digestion limits volatilisation losses of Hg, but Hg is prone to memory effects in ICP-MS, so the Hg values, particularly the single high value in *Tectona grandis*, are interpreted with caution.

2.4 Data analysis

For each tree, a whole-plant concentration was computed as the unweighted mean of its root and leaf values (organ biomass was not measured), and a translocation factor (TF) was computed as the leaf-to-root concentration ratio for each element. TF < 1 indicates net retention in roots and TF > 1 net movement to leaves. Descriptive statistics (mean, standard deviation, median and range) were computed for the indigenous and exotic groups. Because the sample is small and the distributions are skewed, the indigenous–exotic comparison was tested with the two-sided Mann–Whitney U test on tree-level whole-plant concentrations (n = 6 indigenous, n = 13 exotic). To control the false discovery rate across the four element-wise tests, p-values were adjusted with the Benjamini–Hochberg procedure (Benjamini & Hochberg, 1995) and are reported as q-values; significance was set at $q < 0.05$. No test was applied among individual species, because most are represented by a single tree. Concentrations by site type (dump versus reference forest) are reported descriptively only, because species composition differs between the two site types and is therefore confounded with it. Analyses were performed in Python with the SciPy library.

3 Results

3.1 Element concentrations in indigenous and exotic species

Whole-plant concentrations are summarised by origin group in Table 3 and shown for each tree in Fig. 2. Median As was 0.82 mg kg^{-1} in indigenous trees and 0.22 mg kg^{-1} in exotic trees; median Pb was 0.61 and 0.25 mg kg^{-1}, and median Cd 0.52 and 0.27 mg kg^{-1}. Mann–Whitney tests gave $p = 0.022$ for As ($U = 65.0$), $p = 0.018$ for Pb ($U = 66.5$) and $p = 0.009$ for Cd ($U = 68.0$), and all three differences remained significant after false discovery rate adjustment ($q = 0.029$). Hg did not differ between the groups ($U = 58.0$, $p = 0.106$, $q = 0.106$). Its median was 0.37 mg kg^{-1} in indigenous and 0.18 mg kg^{-1} in exotic trees, and the exotic-group mean (0.31 mg kg^{-1}) was pulled above the median by one high value (Section 3.3).

Of the four elements, Cd had the narrowest spread in both groups (indigenous 0.24–0.71, exotic 0.18–0.33 mg kg^{-1}), whereas As and Hg had the widest. As ranged from 0.21 to 2.24 mg kg^{-1} in indigenous trees and from 0.15 to 1.16 mg kg^{-1} in exotic trees; Hg ranged from 0.14 to 0.47 mg kg^{-1} in indigenous trees and from 0.09 to 1.79 mg kg^{-1} in exotic trees.

Table 3

Whole-plant concentrations (mg kg^{-1} dry weight) of four potentially toxic elements in indigenous and exotic tree species, with results of Mann–Whitney U tests on tree-level values

Element	Indigenous (n = 6) mean ± SD	Indigenous median (range)	Exotic (n = 13) mean ± SD	Exotic median (range)	U	p	q[a]
As	1.09 ± 0.92	0.82 (0.21–2.24)	0.31 ± 0.28	0.22 (0.15–1.16)	65.0	0.022	0.029
Pb	0.70 ± 0.44	0.61 (0.26–1.23)	0.26 ± 0.14	0.25 (0.04–0.57)	66.5	0.018	0.029
Cd	0.49 ± 0.17	0.52 (0.24–0.71)	0.27 ± 0.05	0.27 (0.18–0.33)	68.0	0.009	0.029
Hg	0.33 ± 0.13	0.37 (0.14–0.47)	0.31 ± 0.45	0.18 (0.09–1.79)	58.0	0.106	0.106

Whole-plant value = unweighted mean of the root and leaf concentrations of each tree. SD, standard deviation

[a] Benjamini–Hochberg adjusted p-value

3.2 Root-to-leaf partitioning

Median translocation factors (leaf:root) were 0.96 for As, 0.95 for Pb, 0.99 for Cd and 0.97 for Hg (Fig. 3), so in most trees leaf and root concentrations differed by only a few per cent. TF exceeded one in 1 of 19 trees for As, 4 for Pb, 8 for Cd and 6 for Hg. Most of these values were only slightly above one (1.01–1.19). The exceptions were As in *Acacia siamea* (1.32), Cd in *Entandrophragma angolense* (1.46), and Hg in *Entandrophragma angolense* (1.92) and *Tectona grandis* (2.06), the highest ratio in the dataset. Hg was the only element with a mean TF above one (1.07). Strong root retention (TF < 0.35) occurred in only three cases, all in exotic species: As in *Theobroma cacao* (0.13) and *Tectona grandis* (0.31), and Cd in *Tectona grandis* (0.13).

3.3 Species-level concentrations

Root and leaf concentrations for every tree are given in Table 4. The highest As and Pb were recorded in *Ceiba pentandra* at both dumps where it was sampled (whole-plant As 2.24 and 2.22 mg kg^{-1}; Pb 1.23 and 1.22 mg kg^{-1}). The highest Cd was in *Terminalia superba* (0.71 mg kg^{-1}) and *Triplochiton scleroxylon* (0.59 mg kg^{-1}). The highest Hg was in *Tectona grandis* (whole-plant 1.79 mg kg^{-1}), about four times the next highest value (*Triplochiton scleroxylon*, 0.47 mg kg^{-1}). *Tectona grandis* also had by far the largest excess of leaf over root Hg (leaf 2.42, root 1.17 mg kg^{-1}). Five other trees had more Hg in leaves than in

roots, but in all of them leaf Hg was 0.33 mg kg^{-1} or less. Among the other exotic species, *Acacia mangium* had high As (whole-plant 1.16 mg kg^{-1}), and *Theobroma cacao* had high root As (1.13 mg kg^{-1}) but low leaf As (0.15 mg kg^{-1}). The remaining exotic species (*Acacia auriculiformis*, *A. siamea*, *Leucaena leucocephala*, *Gliricidia sepium*, *Persea americana*, *Solanum torvum*, *Morinda citrifolia*, *Claoxylon indicum* and *Canarium album*) had concentrations below 0.4 mg kg^{-1} for all four elements in both tissues.

Table 4

Root and leaf concentrations (mg kg^{-1} dry weight) of As, Pb, Cd and Hg in each tree, by site and origin

Species	Site	As R	As L	Pb R	Pb L	Cd R	Cd L	Hg R	Hg L
Ceiba pentandra[a]	FET	2.265	2.214	1.198	1.254	0.527	0.524	0.387	0.365
Ficus exasperata[a]	FET	0.268	0.241	0.271	0.259	0.365	0.374	0.191	0.185
Leucaena leucocephala	FET	0.155	0.144	0.322	0.341	0.288	0.294	0.255	0.214
Acacia mangium	FET	1.165	1.145	0.569	0.574	0.274	0.269	0.315	0.325
Claoxylon indicum	MAX	0.154	0.147	0.287	0.274	0.325	0.341	0.185	0.178
Theobroma cacao	MAX	1.125	0.148	0.587	0.362	0.258	0.278	0.298	0.236
Canarium album	MAX	0.153	0.142	0.265	0.205	0.362	0.175	0.168	0.200
Solanum torvum	MAX	0.235	0.218	0.168	0.171	0.241	0.265	0.165	0.177
Ceiba pentandra[a]	FOB	2.265	2.178	1.265	1.184	0.524	0.510	0.365	0.354
Morinda citrifolia	FOB	0.255	0.237	0.274	0.256	0.325	0.316	0.187	0.196
Leucaena leucocephala	FOB	0.148	0.142	0.362	0.284	0.278	0.256	0.236	0.224
Gliricidia sepium	FOB	0.214	0.212	0.177	0.158	0.255	0.246	0.187	0.169
Persea americana	ABN	0.207	0.205	0.258	0.247	0.185	0.178	0.096	0.088
Triplochiton scleroxylon[a]	ABN	0.798	0.759	0.625	0.534	0.598	0.579	0.487	0.459
Acacia auriculiformis	ABN	0.219	0.215	0.165	0.159	0.209	0.207	0.119	0.117
Tectona grandis	ABN	0.434	0.135	0.041	0.030	0.574	0.075	1.172	2.415
Terminalia superba[a]	IT	0.856	0.854	0.674	0.625	0.685	0.744	0.425	0.415
Entandrophragma angolense[a]	IT	0.211	0.202	0.266	0.257	0.195	0.285	0.098	0.188
Acacia siamea	IT	0.211	0.279	0.155	0.152	0.205	0.214	0.112	0.103

R, root; L, leaf. Site codes: FET, Fetish; MAX, Maxam Junction; FOB, Fobinso; ABN, Abenabena; IT, IT Tower Line. Fetish, Fobinso and Abenabena are reclaimed dumps; Maxam Junction and IT Tower Line are reference forests

[a] Indigenous species; all others are exotic

3.4 Concentrations by site type

Mean whole-plant concentrations of all four elements were higher in trees on the reclaimed dumps (n = 12) than in trees in the reference forests (n = 7): As 0.68 versus 0.35 mg kg^{-1}, Pb 0.45 versus 0.32 mg kg^{-1}, Cd 0.34 versus 0.33 mg kg^{-1} and Hg 0.38 versus 0.21 mg kg^{-1}. This comparison is reported without a significance test because the species sampled on the dumps differ from those in the reference forests.

4 Discussion

4.1 Higher accumulation of As, Pb and Cd in indigenous species

The higher As, Pb and Cd concentrations in the indigenous group fit the view that native species, adapted over long periods to local soils, have uptake and tolerance traits that recently introduced species have not developed in the same setting (Boi et al., 2023). Native colonisers of mine spoil have repeatedly been reported to survive on hostile substrates while accumulating appreciable amounts of metals (Kahangwa et al., 2021; Nirola et al., 2016), and the present data place *Ceiba pentandra*, *Terminalia superba* and *Triplochiton scleroxylon* in that category on the Ayanfuri landscape. The result should be read as a property of the species sampled, not as a general rule for native versus exotic trees. The indigenous signal is carried mainly by *Ceiba pentandra* for As and Pb and by *Terminalia superba* and *Triplochiton scleroxylon* for Cd, and the exotic group included one strong As accumulator (*Acacia mangium*), so origin alone does not determine accumulation. The acidic, iron-rich ochrosols of the area (Amponsah et al., 2015) also influence element availability. As in particular is strongly retained on iron and aluminium oxides in weathered tropical soils, which limits its phytoavailability (Mensah et al., 2022), and the moderate As concentrations recorded here, even in the strongest accumulators, are consistent with that constraint.

4.2 Partitioning between roots and leaves

Across the tree community, leaf concentrations were close to root concentrations, with median TFs of 0.95–0.99. Efficient phytoextraction requires TFs well above one, so that metals accumulate in harvestable above-ground biomass (Sheoran et al., 2011), and none of the species sampled meets that condition for As, Pb or Cd. The pattern is closer to what phytostabilisation requires, in which uptake does not lead to enrichment of foliage, litter and browse (Bolan et al., 2011; Mendez & Maier, 2008). The evidence for active root retention is weak, however. TFs just below one indicate near-equal partitioning, and strong exclusion from leaves was seen in only three cases, all in exotic species. In the indigenous accumulators, leaves carried almost the same concentrations as roots, so their litter would return As, Pb and Cd to the dump surface at close to root-tissue concentrations. Whether that flux matters depends on litter production and on substrate concentrations, neither of which was measured. Root-retaining native plants have been recommended for stabilising mine tailings elsewhere (Mendez & Maier, 2008; Nirola et

al., 2016); the present data suggest that this property should be measured for each candidate species rather than assumed.

The interpretation is further limited by the absence of soil data. Without substrate concentrations, bioaccumulation factors cannot be calculated, so the fraction of the available element pool taken up by each species is unknown, and root uptake cannot be distinguished from surface adsorption of metal-bearing dust on roots and leaves (Kabata-Pendias, 2011). What the data support is a statement about partitioning within each tree, not a quantitative claim about remediation efficiency. Confirming a stabilisation role requires paired soil and tissue sampling, with sequential extraction to establish bioavailable pools and transfer factors.

4.3 Mercury and Tectona grandis

Hg departed from the other three elements in two respects: it showed no indigenous–exotic difference, and it was the only element with a mean TF above one. Both features owe much to a single exotic tree, *Tectona grandis* (teak), which accumulated far more Hg than any other tree and held about twice as much in its leaves as in its roots (TF = 2.06). *Entandrophragma angolense* had a similar ratio (1.92), but at concentrations below 0.2 mg kg^{-1}. Foliar Hg enrichment is plausible because much of the Hg in leaves comes from atmospheric uptake through the stomata rather than from root uptake and translocation (Wang et al., 2020; Zhou et al., 2021), so a species with high foliar Hg need not be an efficient root extractor. A tree that concentrates Hg in harvestable leaves could be of interest for managing Hg-contaminated ground in gold-mining areas. That possibility is offered here only as a hypothesis: it rests on a single individual, and the Hg determinations are the least secure in the dataset for the reasons given in Section 2.3. Sampling of several teak individuals with a Hg-specific analytical protocol, together with measurements of atmospheric and soil Hg, would be needed before any recommendation could be made.

4.4 Site-type pattern

Trees on the reclaimed dumps had higher mean concentrations of all four elements than trees in the reference forests. This is the direction expected if rehabilitated substrates remain more enriched than the surrounding forest soils several years after closure, as reported for revegetated tailings on a former gold mine in Ghana (Petelka et al., 2019). The pattern is descriptive only. Different species grow on the dumps and in the reference forests, so site type and species identity are confounded, and one of the three dumps, Abenabena, is a former domestic-waste landfill rather than a mine-waste dump (Table 1). Separating the effects of substrate and species would require the same species to be sampled across both site types with adequate replication.

4.5 Limitations

Several limitations bound the conclusions. There is no soil or substrate analysis, so transfer and bioaccumulation factors cannot be computed and the uptake pathway cannot be resolved. Replication within species is limited: 17 species are represented by 19 trees, most by a single individual at a single

site, so differences between species are described but not tested, and the group comparison rests on 6 versus 13 trees. Root and leaf tissues of the same tree are paired measurements of one individual and are treated as such. The whole-plant value is an unweighted mean of two organs and does not represent the total element burden of the tree. The indigenous–exotic and dump–forest contrasts are both confounded with species identity. Full analytical quality-control data were not available, and the Hg results in particular are indicative. These constraints place the study in the category of exploratory screening, and its findings are best regarded as hypotheses for confirmatory testing.

4.6 Implications for rehabilitation practice

Within those limits, the results have a practical message. On this landscape, indigenous species accumulated more As, Pb and Cd than exotic species and, like the tree community as a whole, did not concentrate these elements in their foliage. This supports giving native species such as *Ceiba pentandra*, *Terminalia superba* and *Triplochiton scleroxylon* a larger place in phytostabilisation trials on rehabilitated dumps, and it agrees with calls to base species selection for mine sites on measured accumulation and partitioning rather than on growth performance alone (Kahangwa et al., 2021; Sheoran et al., 2011). Fast-growing exotics keep a role as early cover for erosion control, where their low accumulation is no disadvantage, and teak deserves separate study for Hg. These are recommendations for weighting species choice and for directing further work. They do not show that any species has remediated these sites; that would require the soil-paired, replicated and quality-controlled study this screening exercise is meant to motivate.

5 Conclusions

As, Pb, Cd and Hg were screened in the roots and leaves of 17 tree species growing on three reclaimed waste dumps and in two reference forests within a gold-mine concession at Ayanfuri, Ghana. Indigenous species had significantly higher As, Pb and Cd concentrations than exotic species, while Hg did not differ between the groups. Across the tree community, leaf concentrations were close to and usually slightly below root concentrations (median TF 0.95–0.99), so none of the elements was concentrated in foliage, but strong root retention was rare. *Ceiba pentandra* was the strongest accumulator of As and Pb, *Terminalia superba* and *Triplochiton scleroxylon* of Cd, and the exotic *Tectona grandis* was a distinct Hg outlier with about twice as much Hg in its leaves as in its roots.

These patterns favour indigenous species for trials of As, Pb and Cd phytostabilisation on rehabilitated dumps, with a possible separate role for teak in Hg management. They do not establish remediation performance, transfer efficiency or uptake pathway, all of which require the paired soil analysis this study did not include. Three steps follow: confirmatory sampling with several trees per species; paired soil characterisation with bioaccumulation and transfer factors; and a Hg-specific analytical protocol to test the teak result. Until then, the advantage of indigenous accumulators shown here should be treated as promising but provisional when species are selected for rehabilitated mine land at Ayanfuri.

Statements and Declarations

Acknowledgments The authors thank Perseus Mining (Ghana) Limited for access to the Edikan concession and for logistical help during field sampling.

Funding No funds, grants or other support were received for conducting this study or preparing this manuscript. Perseus Mining (Ghana) Limited provided access to the Edikan concession and logistical help during field sampling, but had no role in study design, data analysis, interpretation of results or the decision to submit the work for publication.

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

Author contributions O. O. Antobre and E. Acquah conceived and designed the study, supervised field sampling and coordinated the laboratory analysis. A. B. Adu-Gyamfi, V. Kusi-Kyei and N. Dakpo curated the dataset, performed the statistical analysis, prepared the figures and tables, and wrote the first draft of the manuscript. W. A. Asante, S. Boadi and B. A. Gyampoh contributed to the study design and the interpretation of results and revised the manuscript critically for important intellectual content. All authors read and approved the final manuscript.

Data availability All data generated and analysed during this study are included in this published article. The complete tree-level dataset, comprising root and leaf concentrations of As, Pb, Cd and Hg for each of the 19 sampled trees (38 tissue measurements), is given in Table 4. Further enquiries may be directed to the corresponding author.

Ethics approval Not applicable. The study did not involve human participants or animals. Plant material was sampled with the permission of Perseus Mining (Ghana) Limited, the concession holder.

Consent to participate and consent to publish Not applicable.

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Figures

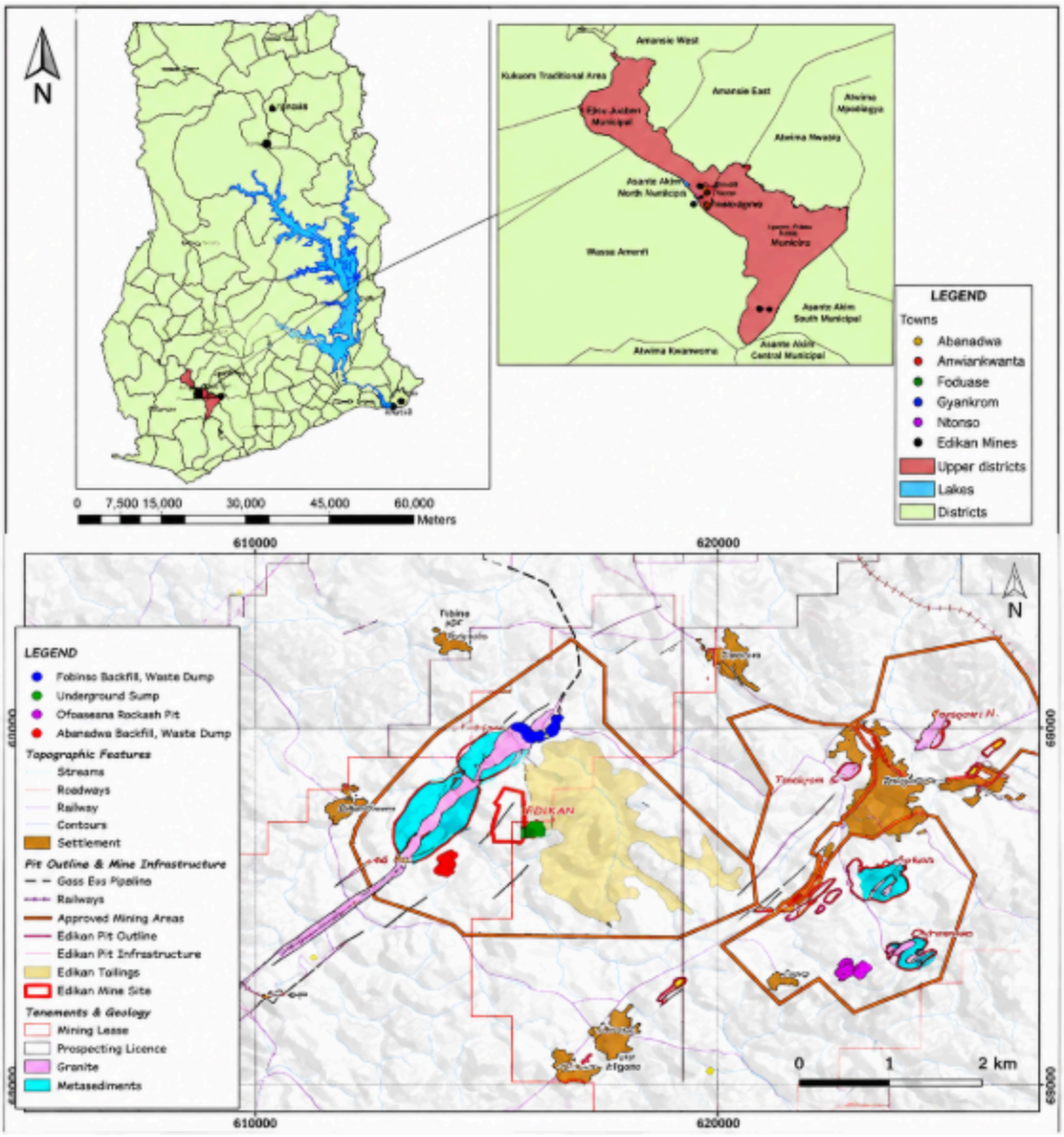


Figure 1

Location of the Edikan concession and the five sampling sites near Ayanfuri, Ghana

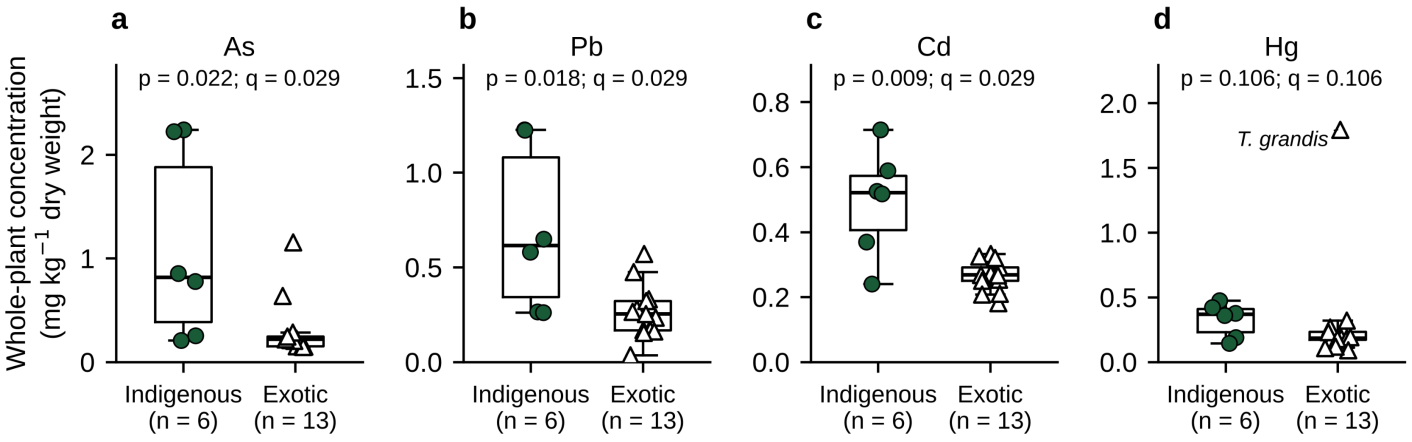


Figure 2

Whole-plant concentrations of (a) As, (b) Pb, (c) Cd and (d) Hg in indigenous (n = 6, filled circles) and exotic (n = 13, open triangles) trees. Boxes show the median and interquartile range; whiskers extend to the most extreme values within 1.5 times the interquartile range. p values are from two-sided Mann–Whitney U tests and q values are Benjamini–Hochberg adjusted

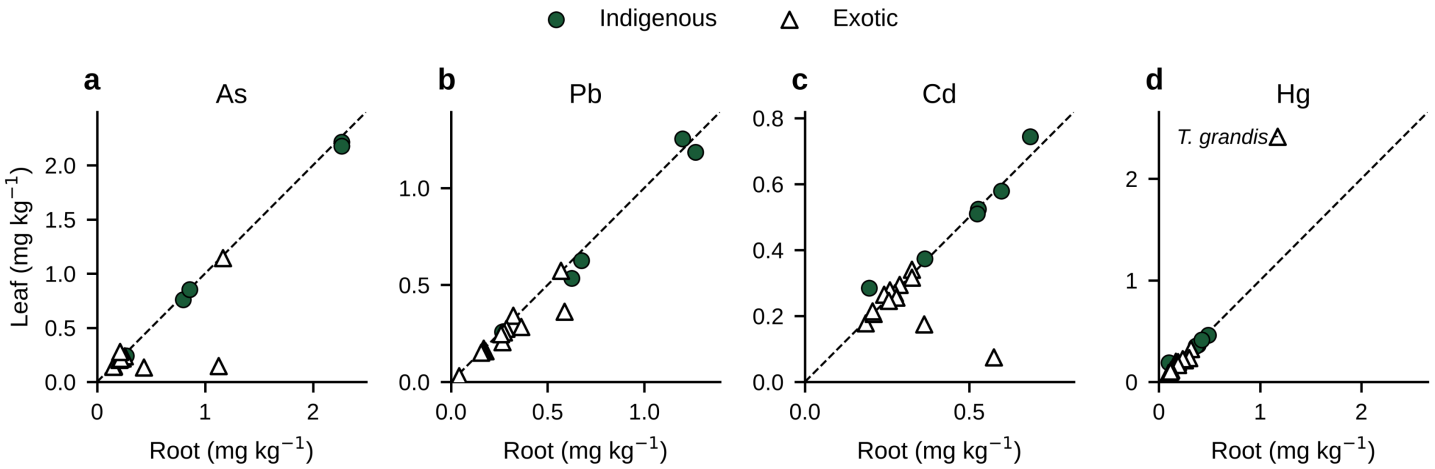


Figure 3

Root versus leaf concentration of (a) As, (b) Pb, (c) Cd and (d) Hg in each tree. Filled circles, indigenous species; open triangles, exotic species. Points below the dashed 1:1 line have a translocation factor below one and points above it a factor above one. The labelled point in (d) is *Tectona grandis*