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Heavy Metals Accumulation by Indigenous Plants Growing in Contaminated Soil in a Gold Mining Area in Ghana

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Abstract
Phytoremediation is an environmentally friendly, low cost biotechnological process that is fast gaining prominence in the cleaning of contaminated soils in the tropics. The accumulative potential of indigenous or native plants for heavy metals in mine tailings at the Storage Facility of the Chirano Gold Mine Limited, Ghana was investigated. Plant species were sampled in five plots, each 32 m^2. Samples of plants were harvested and separated into roots and shoots and the corresponding rhizospheric soil samples collected. They were analysed for the total concentrations of heavy metals; Arsenic (As), Cadmium (Cd) and Zinc (Zn) using Atomic Absorption Spectrophotometer. Bioavailable fractions of studied metals in the soil samples were determined with the formation of metal complex with Ethylenediaminetetraacetic acid and ammonium acetate reagents. The hyper-accumulation potential and mobility of heavy metals within the plants were determined from the bioaccumulation and translocation factors. Differences in mean concentrations of heavy metals in the plants (shoot, root and whole) were separated using Tukey B Analysis of Variance, SPSS version 20, at significant level of $p < 0.05$. The mean concentrations of total and bioavailable As, Cd, and Zn in the soil samples varied with Zinc being most predominant (13.20 mg/kg). However, As was the most available with 39% bioavailability. The soil elemental concentrations of As (3.0 mg/kg), Cd (0.29 mg/kg) and Zn (13.20 mg/kg) were below the WHO recommended standards of 12 mg/kg, 1.4 mg/kg and 200 mg/kg for As, Cd and Zn respectively. The concentrations of all metals in the plant organs varied between species. In all plant species Zinc was the most accumulated heavy metal, recording the highest level of accumulation (135.76 mg/kg) in the root of *Euphorbia heterophylla*. Bioaccumulation factor as expressed by total and bioavailable metal concentrations in soil indicate that all the plant species demonstrate good hyperaccumulation and phytostabilisation potential for Zn and Cd whilst 13 and 8 plant species demonstrate good phytoextraction potential for As. The translocation factor indicate that 8 plant species are good phytostabilisers for Zn, 7 plant species for Cd and 10 plant species for As. The accumulative and phytostabilisation potential of these plant species provide useful information about their selective exploitation for effective phytoremediation of the tailings dam at Chirano Gold Mine.
Keywords: phytoremediation, heavy metal, hyperaccumulation, phytostabilisation, indigenous plants, bioavailable.

1. Introduction

In Ghana mining activities generate lots of hazardous wastes including mine tailings containing heavy metals that can severely affect the ecosystem. Heavy metal absorption into biological systems can cause various degrees of damage to the environment, plants, animals and humans which can lead to loss of biodiversity (Oppong 2011; Wong 2003). The persistence, non-degradability and toxic nature of heavy metals pose a serious threat to human health. The risk herein is potential accumulation of these contaminants by plants resulting in phytotoxicity and human diseases like diarrhoea, cancer, stomach cramps, nausea, anaemia, kidney damage and even brain damage (Mendez 2007; Järup 2003).

Recently, there have been considerable efforts toward remediating metals-contaminated soils in the environment (Vassilev *et al*. 2004; Jieng-feng *et al*. 2009). Conventionally, either on-site management or encapsulation is known for remediating heavy metal contaminated soils. However, neither of these methods solves the issue of decontamination but rather introduces secondary contamination at the dump site (Pulford and Watson, 2003). Using chemicals to immobilize metals in contaminated soils is not an option for many developing countries. This approach is expensive (Mwegoha 2008) and can be destructive to the soil structure and fertility (Pulford & Watson, 2003).

Any development in the area of environmental restoration must be affordable, sustainable and environmentally friendly just like many phytoremediation strategies (Abdullah & Sarem 2010; Rajakaruna *et al*. 2006). This method has drawn public attention nowadays. It does not require expensive equipment or highly specialized personnel, and is easily implemented and maintained. It also provides the opportunity for phytomining of metals (Chehregani *et al*. 2009).

Cleaning mine tailings using plants, however, remains a problem that must be addressed with correct selection of local plant species that can grow on land of marginal quality. The emerging approach to phytoremediation involves the introduction of highly tolerant species that can survive on soils with marginal water, minerals and mixture of metals present (Wong 2003). These plants must have high biomass production,

capable of accumulating 0.5 to 1% of metals in their dry weight (Boateng 2014). The selection of indigenous hyperaccumulator species must also be a matter of concern. Plants should be site-specific and conscious effort should be made to comply with regulations restricting the introduction of foreign species that can be invasive and competitive (Mwegoha 2008).

For successful and effective phytoremediation programmes to be achieved, plants of phytoremediation potential must be identified and used. Thus, studies that screen plants for their potential to phytoremediate contaminated soils are desirable. The aim of this study is to determine the metal accumulation potential of plant species growing in contaminated soil in a gold mining area in Ghana. The ability of these plants to accumulate heavy metals at concentrations higher than that in the soil and transport them within the plants was evaluated. To achieve this objective, soil and plant samples from a contaminated gold mining area were collected and analysed for their heavy metal contents of Arsenic, Cadmium and Zinc.

2. Materials and Methods

2.1 Preparation of samples for laboratory analysis and determination of soil pH

Plant species growing on contaminated mine tailings were harvested from five sampling plots, each 32 m^2 within the concession of a gold mining company. Soil samples around the roots (rhizosphere) of the harvested plants were collected and homogenized and unwanted materials removed. Both plant and soil samples were transported to the laboratory in labelled packets. Plant samples were washed with tap water to remove soil and then rinsed with distilled deionised water. The roots were separated from the shoots with a stainless steel knife. They were air-dried for one week at room temperature by spreading them on thin cellophane paper, followed by oven-drying at 50°C for 48 hours. The homogenized soil sample was air dried for one week at room temperature and oven dried at 50°C for 48 hours to constant weight. The dried soil sample was then pulverized and sieved through 2 mm fine mesh and kept at 4°C in dark plastic bags until analysed. Soil sample (10 g) was dissolved in water at a ratio of 1:1 (w/v) soil: distilled deionised water to determine pH using Hanna instrument 211 pH meter. Deionised water (50 ml) was added and the suspension shaken manually at 15 min intervals for 1 hour to allow soluble salts to dissolve and ionic exchange to reach equilibrium before the pH determination.

2.2 Soil chemical analysis

Soil sample for the determination of total As, Cd and Zn was placed in a crucible and ashed in a furnace at 65°C for 2 hours. The dried sample was ground using a mortar and pestle, and sieved through a 2 mm plastic mesh sieve. For analysis, 1 g of the soil sample was weighed into a beaker and 3 ml of HCl and 1 ml of concentrated HNO_3 were added. The mixture was heated on a hot plate at 100°C for 10 minutes, to destroy any oxidizable materials and carbonates, and left to cool at room temperature. The sample was then diluted with 50 ml deionized water and filtered with a Whatman filter paper (Grade No. 41) before analysis for total As, Cd and Zn using flame Atomic Absorption Spectrophotometer (AAS-VGP 210). For the extractable (bioavailable) fraction of As, Cd and Zn in the soil, 1 g of the soil sample was placed in a measuring beaker and 25 ml of EDTA and ammonium acetate were added, shaken for 2 hours and topped with 50 ml deionized water and filtered through a Whatman filter paper (Grade No. 41) before analysis for extractable As, Cd and Zn using AAS-VGP 210.

2.3 Plant chemical analysis

Oven dried plant samples were put in different crucibles and ashed in a furnace at 65°C for 2 hours. A quantity of the ash (1 g) from each plant sample was weighed separately into a beaker. To each, 3 ml of concentrated HCl and 1 ml of concentrated HNO_3 were added, and heated on a hot plate at 100°C for 10 minutes and left to cool at room temperature. The solutions were topped with distilled deionized water to the 50 ml mark and filtered through a Whatman filter paper (Grade No. 41) prior to determination of As, Cd and Zn using AAS-VGP 210.

2.4 Accumulation ratios

The plants' ability to accumulate heavy metals from the soil was determined by the ratio concentration of heavy metals in plant to the heavy metal concentration in soil (Nazir *et al*. 2011) known as bioaccumulation factor, i.e. BF = [Metal] plant / [Metal] soil. Plants with a high BF value (BF>1) are potential hyperaccumulators and suitable for phytoextraction.

Translocation factor (TF) was described as the ratio of heavy metal concentration in plant shoot to that in plant root (Zacchini *et al*. 2009), i.e. TF = [Metal] shoot / [Metal] root and it was estimated from the bioaccumulation factor of available As, Cd and Zn in shoot compared to concentration in root. Plants with TF>1 are good phytotranslocators/phytostabilisers.

2.5 Statistical analysis

Mean concentrations of heavy metals in the plants organs (shoot, root and whole plant) were computed using Microsoft Excel 2010. Mean differences between concentrations of heavy metals in the plants were compared

using Tukey-B One-Way Analysis of Variance (ANOVA) at a significance level of 5%. The ANOVA was run using SPSS version 20.

3. Results

3.1 Levels of heavy metals and pH in the mine tailings at Chirano

The concentrations of metals in the soil were below the WHO recommended standard for agricultural soils whilst the pH was within the recommended range (Table 1). Available Arsenic concentration of 1.21 mg/kg was 39% of its total concentration in the soil. The total Cadmium concentration of 0.29 mg/kg was six times more than its available concentration in the soil. Zinc recorded the highest total metal concentration of 13.20 mg/kg. This was five times more than its available metal concentration.

Table 1. Mean pH and heavy metal concentrations (mg/kg) in the soil

Parameter	As	Cd	Zn	pH
Total	3.08 ± 0.04	0.29 ± 0.02	13.20 ± 0.06	7.08 ± 0.01
Available	1.21 ± 0.04	0.05 ± 0.00	2.76 ± 0.08	
%Available	39.29	17.24	20.90	
WHO Standard	12	1.4	200	6-8

3.2 Mean concentration of Arsenic, Cadmiun and Zinc in plant species

The mean concentrations of Arsenic, Cadmium and Zinc in mg/kg in plant species are presented in Table 2. The levels of As accumulation in the whole plant for all plants species was higher than that of the standard reference (Markert 1991b) and varies amongst plants species. The highest As concentration in roots was recorded in *Alchornea cordifolia* at 1.55 mg/kg. The lowest As concentration in root was recorded in three plants (*Chromolaena odorata*, *Tridax procumbens* and *Euphorbia hyssopifolia*) at 0.10 mg/kg which is comparable to the standard of "reference plant" (Markert 1991b). Concentration of As in the shoot of *Digitaria gayana* was highest at 2.09 mg/kg whilst the lowest was obtained in 3 plant species (*Conyza sumatrensis*, *Digitaria horizontalis* and *Spigella anthelmia*) at 0.10 mg/kg. Within the whole plant As concentration was highest in *Digitaria gayana* at 2.20 mg/kg whereas the lowest concentration was recorded in *Echinochloa colona* (0.27 mg/kg). In all the plant species, the accumulative levels of As in the plant organs varied between species, indicating selectivity of organ accumulation.

Levels of Cd in both plant organs and whole plant of all plant species were above the standard reference. The highest concentration of Cd in roots (3.21 mg/kg) was determined in *Pteris vittata* whilst the least (0.30 mg/kg) was found in *Spigella anthelmia*. In the shoot of *Solanum erianthum* Cd concentration (3.04 mg/kg) was tenfold greater than that of *Bryophyllum pinnatum* (0.33 mg/kg) whilst within the entire plant of *Smilax anceps* Cd level was quite significant at 5.29 mg/kg. Similarly, as observed with As, concentrations of Cd in both plant organs and within the entire plants varies among species, indicating selectivity. Most of the plants species had higher concentrations of Cd in the roots than in the shoots.

The highest concentration of Zn within the whole plant was recorded in *Euphorbia heterophylla* (186.49 mg/kg). It was eight times greater than the concentration in *Pteris vittata* (23.02 mg/kg). As observed with As and Cd, concentrations of Zn in both plant organs and within the entire plants varies and differs significantly among species, also an indication selectivity. The highest concentration of Zn (135.76 mg/kg) was recorded in the root of *Euphorbia heterophylla* and was lowest (12.24 mg/kg) in roots of *Rhynchelytrum repens*, whilst the shoot of *Smilax anceps* accumulated 91.97 mg/kg of Zn, twelvefold greater than its concentration in *Alchornea cordifolia* shoot (7.58 mg/kg).

Table 2. Mean concentrations of Arsenic, Cadmium and Zinc in plant species

Species	Arsenic (mg/kg)			Cadmium (mg/kg)			Zinc (mg/kg)		
	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole
Alchornea cordifolia	1.55±0.01^{k}	0.12±0.02^{a}	1.67±0.03^{j}	1.57±0.56^{c}	1.54±0.01^{d}	3.11±0.55^{d}	114.20±1.42^{o}	7.58±0.23^{a}	121.78±1.19^{l}
Bryophyllum pinnatum	0.44±0.02^{d}	0.11±0.01^{a}	0.54±0.02^{c}	2.21±0.01^{ef}	0.33±0.02^{a}	2.54±0.01^{b}	20.37±0.34^{d}	30.84±0.0.52^{i}	51.21±0.86^{e}
Chromolena odorata	0.10±0.01^{a}	1.53±0.02^{h}	1.63±0.01^{j}	1.53±0.03^{c}	0.90±0.01^{b}	2.43±0.03^{b}	16.16±0.17^{c}	25.16±0.32^{g}	41.32±0.0.48^{c}
Conyzasumatrensis	0.77±0.02^{h}	0.10±0.00^{a}	0.87±0.02^{f}	1.44±0.01^{c}	1.07±0.03^{c}	2.51±0.03^{b}	23.76±0.27^{e}	40.04±0.07^{j}	63.80±0.32^{h}
Digitaria gayana	0.11±0.01^{a}	2.09±0.02^{j}	2.20±0.03^{l}	1.35±0.00^{c}	0.41±0.01^{a}	1.76±0.01^{a}	53.98±0.26^{m}	44.12±0.14^{k}	98.05±0.30^{k}
Digitaria horizontalis	1.10±0.01^{a}	0.10±0.02^{a}	1.20±0.02^{g}	1.95±0.01^{d}	2.86±0.01^{j}	4.81±0.05^{h}	45.41±0.49^{k}	88.78±0.12^{q}	134.19±0.58^{n}
Digitaria insularis	0.66±0.01^{f}	0.15±0.02^{a}	0.81±0.01^{e}	2.51±0.04^{g}	2.26±0.03^{g}	4.77±0.07^{g}	40.84±0.02^{i}	24.59±0.26^{h}	65.43±0.31^{i}
Echinochloa colona	0.16±0.01^{b}	0.11±0.01^{a}	0.27±0.02^{a}	2.29±0.02^{fg}	0.79±0.01^{b}	3.08±0.02^{d}	37.07±0.12^{h}	19.14±0.02^{e}	56.21±0.13^{g}
Eragrostis tremula	0.12±0.02^{a}	0.34±0.02^{b}	0.46±0.03^{b}	2.62±0.02^{hi}	1.10±0.00^{c}	3.72±0.02^{e}	42.19±0.37^{j}	83.37±0.35^{p}	125.56±0.35^{m}
Euphorbia heterophylla	0.72±0.03^{g}	0.76±0.02^{e}	1.48±0.03^{h}	1.90±0.01^{d}	2.71±0.03^{h}	4.61±0.03^{f}	135.76±1.02^{p}	50.73±0.10^{m}	186.49±1.11^{q}
Euphorbia hyssopifola	0.10±0.02^{a}	0.32±0.02^{b}	0.42±0.02^{b}	1.63±0.02^{c}	2.75±0.01^{h}	4.38±0.02^{f}	90.64±0.6^{n}	49.11±0.10^{c}	139.75±0.13^{o}
Mimosa pudica	0.12±0.02^{a}	1.64±0.02^{i}	1.76±0.03^{k}	1.36±0.01^{c}	1.54±0.18^{d}	2.90±0.18^{c}	26.66±0.21^{f}	21.24±0.01^{f}	47.90±0.22^{d}
Paspalum	0.13±0.04^{b}	0.60±0.02^{d}	0.73±0.03^{e}	2.73±0.03^{i}	1.77±0.03^{e}	4.50±0.05^{f}	46.65±0.12^{l}	18.31±0.10^{d}	64.96±0.17^{h}
Pteris vittata	0.33±0.02^{b}	1.22±0.03^{g}	1.55±0.05^{i}	3.21±0.02^{j}	1.57±0.04^{d}	4.78±0.04^{h}	13.68±0.09^{b}	9.34±0.16^{b}	23.02±0.07^{a}
Rhynchelytrum repens	1.31±0.01^{j}	0.12±0.02^{a}	1.43±0.03^{h}	1.56±0.02^{c}	1.66±0.04^{d}	3.22±0.05^{d}	12.24±0.18^{a}	57.53±0.09^{n}	69.77±0.26^{j}
Smilax anceps	0.73±0.04^{g}	0.11±0.02^{a}	0.84±0.06^{f}	3.17±0.03^{j}	2.12±0.03^{f}	5.29±0.03^{i}	54.02±0.07^{m}	91.97±0.07^{r}	145.99±0.12^{p}
Solanum erianthum	0.52±0.03^{e}	0.92±0.02^{f}	1.44±0.03^{h}	0.85±0.02^{b}	3.04±0.06^{k}	3.89±0.05^{e}	19.38±0.54^{d}	14.57±0.24^{c}	33.95±0.37^{b}
Spigella anthelmia	0.64±0.02^{f}	0.10±0.01^{a}	1.74±0.03^{k}	0.30±0.01^{a}	2.29±0.07^{g}	2.59±0.07^{b}	40.64±0.37^{i}	81.24±0.06^{o}	121.88±0.40^{l}
Tridax procumbens	0.10±0.01^{a}	0.52±0.02^{c}	0.63±0.02^{d}	2.02±0.03^{ef}	2.94±0.05^{i}	4.96±0.05^{h}	31.57±0.05^{g}	21.14±0.13^{f}	52.71±0.14^{f}
Standard	0.10			0.05			50		

Mean ± SD in same column with different letters in superscripts differ significantly ($p<0.05$). Highest and lowest values are in bold font

3.3 Bioaccumulation factor for total and bioavailable As, Cd and Zn in soil compared to concentrations in plants

The bioaccumulation factor, indicative of the selective accumulation potential of heavy metals by plant species, was determined in both organs and the whole plant using the total and bioavailable As, Cd and Zn in soil samples (Table 3). Using the bioavailable concentration gives the mineralized value of the metal that is available to the plant for uptake and a fair evaluation to justify the plant's accumulative potential.

Bioaccumulation factor for total As was less than 1 in all plant species for both plant organs and whole plants. Bioaccumulation factor was greater than 1 in all the plant species for total Cd in roots, shoots and whole plants. Bioaccumulation factor greater than 1 for total Zn was obtained in roots of 18 plant species, in the shoots of 17 plant species and 19 plant species when the Zn concentrations in whole plants were compared against levels in soils.

All the plant species recorded bioaccumulation factor greater than 1 for available Zn and Cd (Table 3). Bioaccumulation factor greater than 1 for available As was obtained by 2 plant species (*R. repens* and *A. cordifolia*) in the roots, 4 plant species (*C. odorata*, *M. pudica*, *P. vittata* and *D. gayana*) in the shoots and 8 plant species (*C. odorata*, *M. pudica*, *R. repens*, *E. heterophylla*, *P. vittata*, *D. gayana*, *S. erianthum* and *A. cordifolia*) in the whole plants. Generally, in this study the bioaccumulation factors for As, Cd and Zn uptake in all plant species increased by factors of 2.5, 6 and 5 respectively when the available forms of heavy metals in soils are used to determine the factor as compared to the total fractions.

Table 3. Bioaccumulation factors for total and bioavailable As, Cd and Zn in soil compared to concentrations in plants

Species	As						Cd						Zn					
	Total			Bioavailable			Total			Bioavailable			Total			Bioavailable		
	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole	Root	Shoot	Whole
Alchornea cordifolia	0.50	0.04	0.54	1.28	0.10	1.38	5.41	5.31	10.72	31.40	30.80	62.20	8.65	0.57	9.23	41.43	2.75	44.17
Bryophyllum pinnatum	0.14	0.04	0.18	0.36	0.09	0.45	7.62	1.14	8.76	44.20	6.60	50.80	1.54	2.34	3.88	7.39	11.19	18.58
Chromoleana odorata	0.03	0.50	0.53	0.08	1.27	1.35	5.27	3.10	8.37	30.60	18.00	48.60	1.22	1.91	3.13	5.86	9.13	14.99
Conyza sumatrensis	0.25	0.03	0.28	0.64	0.08	0.72	4.97	3.69	8.66	28.80	21.40	50.20	1.80	3.03	4.83	8.62	14.52	23.14
Digitaria gayana	0.03	0.68	0.71	0.09	1.73	1.82	4.66	1.41	6.07	27.00	8.20	35.20	4.09	3.34	7.43	19.23	15.99	35.54
Digitaria horizontalis	0.36	0.03	0.39	0.91	0.08	0.99	6.72	9.86	16.58	39.00	57.20	96.20	3.44	6.73	10.17	16.47	32.21	48.68
Digitaria insularis	0.21	0.05	0.26	0.54	0.12	0.66	8.66	7.79	16.45	50.20	45.20	95.40	1.86	3.09	4.96	14.81	8.92	23.74
Echinochloa colona	0.05	0.03	0.08	0.13	0.09	0.22	7.89	2.72	10.61	45.80	15.80	61.60	2.81	1.45	4.26	13.45	6.94	20.39
Eragrostis tremula	0.04	0.11	0.15	0.10	0.28	0.38	9.03	3.79	12.82	52.40	22.00	74.40	3.20	6.32	9.52	15.30	30.24	45.55
Euphorbia heterophylla	0.23	0.25	0.48	0.59	0.63	1.22	6.55	9.34	15.89	38.00	54.20	920.20	10.29	3.84	14.13	49.25	18.40	67.65
Euphorbia hyssopifolia	0.03	0.10	0.13	0.08	0.26	0.34	5.62	9.48	15.10	32.60	55.00	87.60	6.87	3.72	10.59	32.88	17.82	50.70
Mimosa pudica	0.04	0.53	0.57	0.10	1.35	1.46	4.68	5.31	9.99	27.20	30.80	58.00	2.02	1.61	2.63	9.67	7.71	17.38
Paspalum scrobiculatum	0.04	0.20	0.24	0.10	0.50	0.60	9.41	6.10	15.51	54.60	35.40	90.00	3.53	1.39	4.92	16.92	6.64	23.56
Pteris vittata	0.11	0.40	0.50	0.27	1.01	1.28	11.07	5.41	16.48	64.20	31.40	95.60	1.04	0.71	1.74	4.96	3.39	8.35
Rhycheltrum repens	0.43	0.04	0.47	1.08	0.10	1.18	5.37	5.72	11.09	31.20	33.20	64.40	0.93	4.36	5.29	4.44	20.87	25.31
Smilax anceps	0.24	0.04	0.27	0.60	0.09	0.69	10.93	7.31	18.24	63.40	42.40	105.80	4.09	6.97	11.06	19.60	33.36	52.96
Solanum erianthum	0.17	0.30	0.47	0.43	0.76	1.19	2.93	10.48	13.41	17.00	60.80	77.80	1.47	1.10	2.57	7.03	5.29	12.32
Spigella anthelmia	0.21	0.03	0.24	0.53	0.08	0.61	1.03	7.89	8.92	6.00	45.80	51.80	3.08	6.16	9.24	14.74	29.47	44.21
Tridax procumbens	0.03	0.17	0.20	0.08	0.43	0.51	6.96	10.14	17.10	40.40	58.80	99.20	2.39	1.60	3.99	11.45	7.67	19.12

Values >1 are in bold font

3.4 Translocation factors for As, Cd and Zn concentrations in root compared to concentrations in shoot of plants

Most of the plant species showed selective translocation for the metals (Table 4). Translocation factors greater than 1 was obtained in 8 plant species (*C. odorata*, *R. repens*, *C. sumatrensis, B. pinnatum*, *S. anthelmia*, *E. tremula*, *D. horizontalis and S. anceps*), indicating that they are good phytotranslocators for Zn. *M. pudica*, *R. repens*, *E. heterophylla*, *S. anthelmia*, *T. procumbens*, *D. horizontalis* and *S. erianthum* were indicative for Cd, whilst 8 plant species (*C. odorata*, *M. pudica*, *E. heterophylla*, *E. tremula*, *T. procumbens*, *P. vittata*, *D. gayana* and *P. scrobiculatum*) were good translocators for As. Amongst the 19 plant species, *Digitaria gayana* had the highest TF of 19.22 for As followed by *Chromoleana odorata* and *Mimosa pudica* with translocation factors of 15.88 and 13.50 respectively.

Table 4. Translocation factors for As, Cd and Zn concentrations in shoot compared to root of plants

Species	**Translocation factors**		
	As	**Cd**	**Zn**
Alchornea cordifolia	0.08	0.98	0.07
Bryophyllum pinnatum	0.25	0.15	**1.51**
Chromoleana odorata	**15.88**	0.59	**1.56**
Conyza sumatrensis	0.13	0.74	**1.68**
Digitaria gayana	**19.22**	0.30	0.83
Digitaria horizontalis	0.09	**1.47**	**1.96**
Digitaria insularis	0.22	0.90	0.60
Echinochloa colona	0.69	0.34	0.52
Eragrostis tremula	**2.80**	0.42	**1.98**
Euphorbia heterophylla	**1.07**	**1.43**	0.37
Euphorbia hyssopifolia	**3.25**	**1.69**	0.54
Mimosa pudica	**13.50**	**1.13**	0.80
Paspalum scrobiculatum	**5.00**	0.65	0.39
Pteris vittata	**3.74**	0.49	0.68
Rhylcheltrum repens	0.09	**1.06**	**4.70**
Smilax anceps	0.15	0.67	**1.70**
Solanum erianthum	**1.77**	**3.58**	0.75
Spigella anthelmia	0.15	**7.63**	**2.00**
Tridax procumbens	**5.38**	**1.46**	0.67

Values >1 are in bold font

4. Discussions

The soil in the study area was neutral with a mean pH of about 7.08 (Tab. 1). This pH value was within recommended standard and is suitable for plant growth. Soil pH is a determining factor for the mobility behaviour of heavy metals in soils. Decreasing pH in soils builds the opposition amongst H^+ and broke down metals for ligands, for example, CO_3^{2-}, SO_4^{2-}, Cl^-, OH^-, S^{2-} and phosphates (Jieng-feng *et al*. 2009; Fijalkowski *et al*. 2012). This metal-ligands competition reduces the metal adsorption capacity of soil particles while promoting heavy metals mobility and bioavailability in the soil.

According to WHO (Canadian Council of Ministers of the Environment 1999), even the highest total and available metal concentrations of about 13.20 mg/kg (Zn) and 2.76 mg/kg (Zn) respectively did not exceed the recommended metal concentrations for agricultural soils. In mining areas where best practices of waste management are in place, little or no pollution occur (Nazir *et al*. 2011). Clearly, the sampling area was not polluted with heavy metals according to the reference standards (Table 1).

Generally plants metal concentrations vary from species to species (Lăcătuşu *et al*. 2009) owing to plant response under different environmental conditions (Mganga *et al*. 2011). This assertion was evident in the study as heavy metal concentrations in plants varied from species to species (Table 2). Though it has been suggested that species of the family Euphorbiceae are good for phytoremediation (Messou *et al.* 2013), *A. cordifolia* (Euphorbiceae) recorded the lowest Zn concentration (Table 2). The maximum Cd concentration was found in the root of *P. vittata*. This study confirm report from Xiyuan *et al*. (2007) that *P. vittata* has the capability to survive in Cd contaminated soils.

According to Nazir *et al*. (2011) plants with a high BF value (BF>1) are suitable for phytoextraction or phytoaccumulation. Bioaccumulation factors for both Cd and Zn are greater than 1 in all 19 plant species even with determination using total concentrations of heavy metals in soils. This is indicative of the plants high, selective affinity for the uptake of these metals. However, none of the plant species had bioaccumulation factor greater than 1 for total As in neither of roots and shoots or whole plant (Table 3). According to Sherene (2010) the metal available concentration the in soil may be a better predictor for environmental impact of historical and current emissions of metals in a contaminated area. This statement was evident in the study. Though the bioaccumulation factor of total As in soil compared to concentrations in plants showed no Arsenic accumulation in any of the plants, the bioaccumulation factor of available As in soil compared to concentrations of As in the plants indicated otherwise. The tolerance capacity of the plants for the selective uptake and accumulative potential was evident when the bioaccumulation factor is determined using the concentrations of available As in the soil. Thus, there was As bioaccumulation within the whole plant body by 8 plant species, in the roots by 2 species and in the shoots by 3 species. This indicates that the bioaccumulation factor gives a more realistic index of evaluation for heavy metals extraction in contaminated areas if concentrations within plants are compared to available forms in soils.

Since the concentration of bioavailable heavy metal is a better predictor of historic and present discharges of metals in a contaminated area (Sherene 2010), and used in this study in the determination of the bioaccumulation factor and subsequently translocation factor, the effective potential of the plants to accumulate these heavy metals is realized. According to Yoon *et al*. (2006) heavy metal-tolerant species with high BF (i.e. metal concentration ratio of plant root to soil) and low TF can be used for phytostabilisation of contaminated sites, together with a vegetative cover. Earlier, Susarla *et al*. (2002) have indicated that plants usually deploy this technique (phytostabilisation) in order to immobilize toxic metals in contaminated soils.

5. Conclusion

The results of this study indicates that plants do vary in their capacity to accumulate different metals. All the 19 plant species demonstrate good hyperaccumulation and phytostabilization potential for Zn and Cd whilst 8 plant species show ability of good hyperaccumulation potential for As. The translocation factor indicates that 8 plant species are good phytostabilizers for Zn, 7 plant species for Cd and 10 plant species for As. The accumulative and phytostabilization potential of these plant species provide useful information about their selective exploitation for effective phytoremediation of the tailings dam at Chirano Gold Mine and similar mining areas. Suggested future studies should consider potted experiment using some selected plants, particularly *E. heterophyll*a, *D. horizontalis* and *D. gayana*.

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