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The Potential of Bioaccumulation and Translocation of Heavy Metals in Plant Species Growing around the Tailing Dam in Tanzania

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ABSTRACT

The present paper covers the probability of heavy metals bioaccumulation and translocation in twelve plant species growing around the tailing dam of North Mara gold mine. In the present study about 5 g of root and shoot portions of the randomly selected plant species that were growing around the tailing dam were separately collected. Besides, 10 g of soil samples were also collected from the rhizosphere at each sampling point where vegetations were previously sampled. The soils and vegetations were analyzed for four heavy metals (lead, zinc, cadmium and nickel) by Atomic Absorption Spectrophotometer. Bioaccumulation potential was measured in the plant species by calculating Bioaccumulation Factor (BAF). BAF was obtained from the ratio of metal content in plant roots to that of total metal content in the soil. Besides, translocation potential was determined by calculation of Translocation Factor (TF), which was obtained from the ratio of the metal content in the plant shoots to that in the plant roots. Of the studied plants, only Gomphrena celosioides L., Hibiscus nicranthus L., Indigofera cuneata Bak., Acacia albida Bentha. and Cynodon dactylon (L.) Pers. had BAF and TF > 1, suggesting their applicability in extraction of the studied heavy metal-polluted soils at the study area. Since heavy metal accumulation and subsequent translocation depends on climatic and edaphic factors, more local plants which are capable of accumulating heavy metals need to be identified and tested in situ.

Keywords: *Bioaccumulation factor; heavy metals; plant species; rhizosphere soil; translocation* factor

1. INTRODUCTION

Natural mineral deposits containing particularly large quantities of heavy metals are present in many regions of the world. It follows that many heavy metals occur naturally in all soils in at least trace quantities. However, the levels of heavy metals in soils are greatly increased by human activities such as mining [1].

Gold mining in Tanzania takes place mainly at three goldfields, namely; Lupa Goldfield, Mpanda Mineral Field and Lake Victoria Goldfield. Of these, Lake Victoria Goldfield ranks high and produces over 90% of gold in Tanzania [2]. North Mara gold mine falls in the Musoma-Mara Greenstone Belt which is part of the Lake Victoria Goldfield [3]. The supracrustal assemblages that make up the Musoma-Mara Greenstone Belt include (from the lowermost) mafic volcanic, lower felsic volcanic and upper felsic volcanic rocks overlain by sedimentary rocks aging between ~2676 and ~2667 million years ago [4]. Available literature indicates that gold deposits in the vicinity of North Mara gold mine are associated with sulfide rocks that are contaminated with heavy metals such as lead, zinc, chromium, cadmium and nickel [5].

Residues from gold mines are both solid materials as waste rocks that result from drilling and blasting of rocks, and the liquid materials resulting from gold processing that are disposed of in the dam as tailings. Tailings are remains of the processed ore while waste rocks are rocks on surfaces of pits that have no ore [6]. Heavy metals from tailing dams and waste rock piles can cause prevalent pollution of soils and sediments in the vicinity of mining areas [7]. Globally, the accumulation of heavy metals in ecosystems is of increasing concern due to environmental problems which are associated with the metal pollution. Under elevated levels in the environment, for example in the soil heavy metals extensively affect plant growth and human health [8, 9]. Plant contamination by heavy metals is mainly caused by the more mobile chemical species, as long as they are easily absorbed by plants [10]. Due to the risks of heavy metals, plants like other living organisms learn to adapt to the novel environment through specific mechanisms; accumulation and exclusion. Such adaptations may be acquired over short time or long time periods [11]. Phytoremediation can provide a cheap, durable and vivid solution for remediation of heavy metal-contaminated areas [12]. One of the strategies of phytoremediation of metal-contaminated soil is phytoextraction, i.e. through uptake and accumulation of metals into plant shoots [13]. This is because the ability of a given plant to accumulate heavy metals from soils can be estimated using the biaccumulation factor, which is defined as the ratio of metal level in the roots to that in soil [14]. Furthermore, the ability of a plant to translocate metals from the roots to the shoots is measured using the translocation factor, which is defined as the ratio of metal level in the shoots to that in the roots.

The present study was carried out so as to explore plant species which have potential for bioaccumulation and/or translocation of heavy metals at North Mara gold mine, the area which has been contaminated with several heavy metals [15, 16].

2. REVIEW OF LITERATURE

Almost all plants require small amount of some heavy metals often referred to as micro-nutrients for their growth and development. These are obtained from the soil and water.

These metals include manganese, iron, magnesium, zinc, copper, molybdenum and nickel [17]. Yet, certain plants have the ability to accumulate heavy metals, such as cadmium, chromium, lead, cobalt, silver and mercury which have no known biological function (s) [18]. Excessive accumulation of these heavy metals however, can be toxic to most plants and to the food chain as a whole. This is because heavy metals entering the ecosystem lead to bioaccumulation and biomagnification along the food chains causing direct consequences to the components of the food chains. Furthermore, heavy metals are not biodegradable thus they persist in the environment. Several studies have focused on the negative impacts of heavy metals on organisms. Table 1 summarizes the negative influences in plants of the heavy metals that were analyzed during the current study.

Table 1. Hazards from excess lead, zinc, cadmium and nickel

Metal	Effects in Plants
Pb	Inhibits growth, lowers transpiration, interferes with the uptake of essential minerals, lowers chlorophyll content and inhibits photosynthesis
Zn	Chlorosis in young leaves, browning of coralloid roots and serious inhibition on plant growth as a result much reduced fresh and dry weight.
Cd	Inhibits shoot and root growth, inhibits chlorophyll formation, interferes with the absorption of essential minerals and negatively affects the plant-water relations
Ni	Decrease in growth; interveinal chlorosis followed by necrosis, reduction in chloroplast number and volume, affects pollen development and prevents essential mineral absorption

Sources: [19, 20, 21, 22, 23, 24, 25].

Under normal circumstances, plant species in ecosystems recover from the detrimental effects caused by mining activities [26, 27]. This is because the ability to both tolerate elevated levels of heavy metals and accumulate them in very high levels has evolved both independently and together in a number of different plant species [28].

It follows that mine spoils contain higher levels of heavy metals and might be considered as ecological islands [29], because these areas often support characteristic plant species that thrive in these metal-enriched environments. Plants that grow on mine spoils often evolve tolerances and even obtain the capability of hyperaccumulation under severe stress [30]. According to [31], tolerance to elevated levels of heavy metals is often considered to be the best example of evolutionary changes in plant populations. Hundreds of metal-tolerant genotypes have been identified from the metal-contaminated soils, indicating that the evolution of metal-tolerance is one of the major strategies for plant colonization in mining spoils [32]. Plant succession on such areas will therefore be pioneered by plants that are adapted to tolerating higher levels of heavy metals in the soil which often differ from the original plant species that inhabited the area prior to the commencement of mining activities [29].

Heavy metal accumulation is of ecological importance in such plants because the accumulated heavy metals result in deterrence of consumption by herbivores [33]. About 400 plants that hyperaccumulate metals are reported [27].

3. METHODS

The present study was carried around the tailing dam of North Mara gold mine in Tanzania. The mine is about 100 kilometers east of Lake Victoria and 20 kilometers south of the Kenya-Tanzania border [3]. North Mara gold mine falls in the Lake Victoria Gold Field which is associated with the greenstone belt and sedimentary ores. At this area, waste rocks are disposed of by accumulating them around the tailing dam (Plate 1 (a) & (b)).

(a)

(b)

Figure 1. North Mara gold mine, (a) A portion of the tailing dam partly surrounded by rock piles (b) Rock piles surrounding the tailing (tailing not seen)

Source: Field work

Sampling was done around the tailing dam which is surrounded by piles of remnant rocks after gold recovery (Figure (a)-(c)). The site is located between latitudes 1º28' S and 1º27' S and along longitudes 34º29' E and 34º28' E (Figure 2).

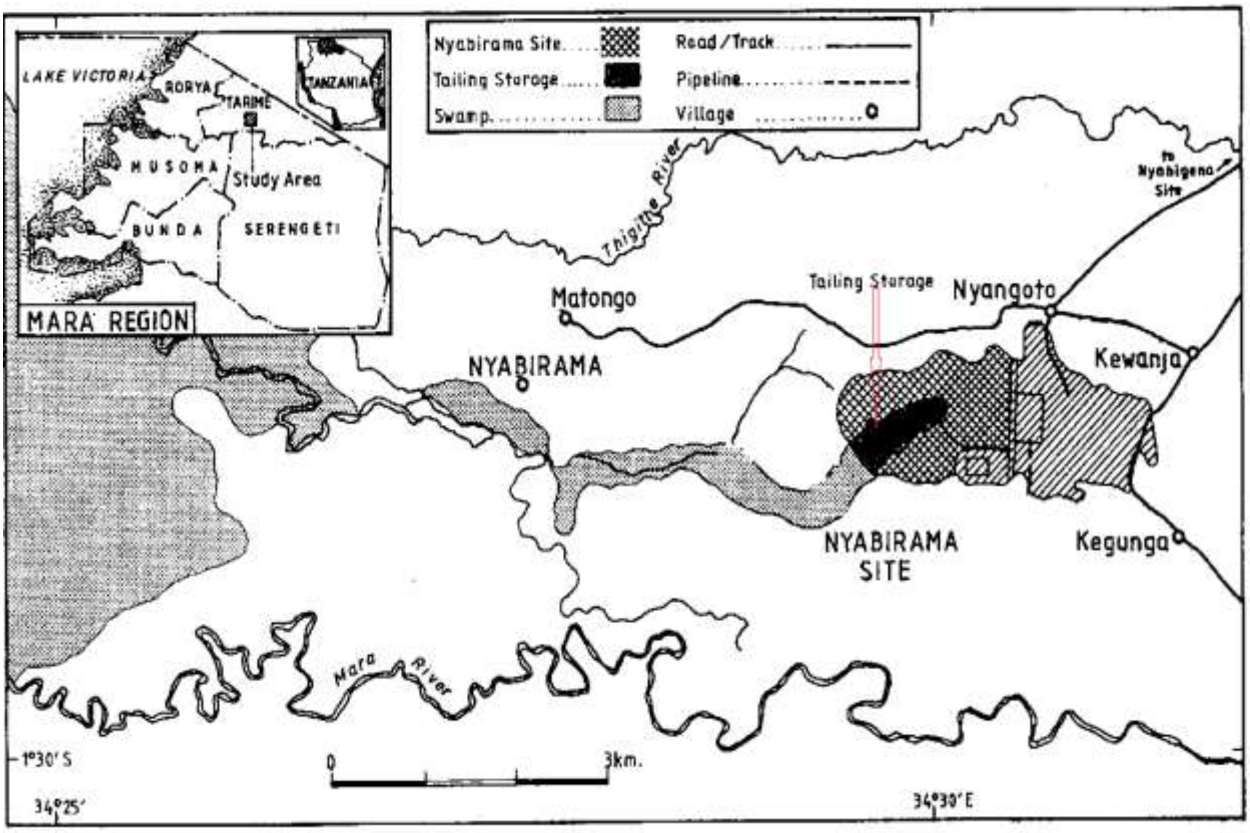

Figure 2: Location of the tailing dam around North Mara gold mine

A total of 12 plant species were randomly collected for analysis of their heavy metal content. Many of these were herbs and grasses as the vegetation around North Mara Gold Mine is typically open grassland. In addition, whole populations of these plants have been said to become resistant to heavy metals within only a few years [34]. Approximately 5 g of the root and shoot portions were separately taken from each of the sampled plants. Identification of the collected plant species was done to family and species level (Table 2).

Table 2. Family for the studied plant species

Plant species	Family
Grewia microcarpa K. Schum.	Tiliaceae
Aerva lanata (L.) Schultes.	Amaranthaceae
Gomphrena celosioides L.	Amaranthaceae
Euphorbia hirta L.	Euphorbiaceae
Cynodon dactylon (L.) Pers.	Gramineae
Eragrostis aethiopica Chiov.	Gramineae
Setaria incrassata (Hochst.) Hack.	Gramineae
Sporobolus pyramidalis P. Beauv.	Gramineae
Acacia albida Bentha.	Mimosaceae
Indigofera cuneata Bak.	Papilionaceae
Hibiscus nicranthus L.	Malvaceae
Cynanchum tubulosum (L. F.) Engl.	Scrophulariaceae

These samples were labelled, air dried and placed in paper bags. Soil samples were also collected from the rhizosphere at each sampling point where vegetations were previously sampled. The collected samples of plants and soils were transported to the Botany Department of the University of Dar es Salaam for laboratory analysis.

In order to determine total levels of heavy metals, the soil samples were air-dried to constant weights. They were then ground into fine powder using pestle and mortar and sieved through 2 mm plastic mesh to avoid metal contamination. From these, sub-samples of 2 g each were taken and digested with 6ml 5:1 nitric acid and perchloric acid mixture following the digestion procedures [35]. The resulting mixtures were then heated in a Kjeldahl Thermo apparatus at 200˚C until complete digestion was achieved. During heating, explosion of the contents was prevented by adding porcelain chips to the digestion tubes. After digestion, samples were left to cool, then to each digestion tube distilled water was added to the 50 ml mark in readiness for heavy metal analysis. To prevent contamination glass and plastic laboratory wares were washed in dilute nitric acid and distilled water. Analysis of the levels of heavy metals was done at the University of Dar es Salaam, College of Engineering and Technology; using a Perkin-Elmer 3100 Atomic Absorption Spectrophotometer. During the analysis, impact beads were used in the spray chamber to increase sensitivity.

Plant root and shoot samples were thoroughly washed by distilled water to remove all adhering soil particles. Samples were then oven dried to constant weights at 105˚C. Each dried sample was ground to powder using a wearing blender (Model type A 10 Janke and Kunkel GBH a Co. KG) [35]. One gram of each sample was used for analysis. These samples were then digested using 5ml of 5:1 of concentrated Nitric (HNO_3) and Perchloric acid ($HClO_4$) mixture according to [35], then heated in a Kjeldahl vessel at 120˚ C until complete digestion was achieved. Subsequent procedures were similar to those for soil samples. Digestion and analytical efficiency of AAS was validated using a standard reference material of tomato leaf (SRM 1573a, National Institute of Standards and Technology, NIST). The percentage recoveries from the analysis of the standard reference material by the procedures that were currently used were 80% Zn, 90% Ni, 83% Pb and 85% Cd.

Data Analysis

Bioaccumulation factor and translocation factor can be used to give a clue on the suitability of the plant in question in phytoremediation. This is because phytoremediation technology uses the potential of heavy metal bioaccumulation and exclusion of plants to cleanup heavy metal polluted areas [36, 37]. In the present study Pb, Zn, Cd and Pb translocation from shoot to root was measured by translocation factor (TF) which is given by:

$$\text{TF} = \frac{\text{Metal level in the shoot}(\mu g/g)}{\text{Metal level in the root}(\mu g/g)} \text{ [18, 38].}$$

Bioaccumulation factor (BAF) of the heavy metals in these plant species was determined by calculating the ratio of metal level in the shoot to that of the soil as:

$$\text{BAF} = \frac{\text{Metal level in the root}(\mu g/g)}{\text{Metal level in the soil}(\mu g/g)} \text{ [14].}$$

RESULTS

Table 3 presents the levels of the studied heavy metals in soils, shoots and roots. The extent of accumulation of heavy metals by the plants studied differed with the type of metal. The highest level of lead of 27950 µg/g was found in the shoot of *Gomphrena celosioides* L., while the lowest level of lead of 122 µg/g was found in the shoot of *Grewia microcarpa* K. Schum. The highest level of zinc of 200 µg/g was found in the root of *Cynanchum tubulosum* (L. F.) Engl., while the lowest level of zinc of 24 µg/g was found in the root of *Grewia microcarpa* K. Schum. Furthermore, the highest level of cadmium of 1100 µg/g was found in the root of *Euphorbia hirta* L., while the lowest level of cadmium of 5 µg/g was found in the root of *Grewia microcarpa* K. Schum. (Table 2). The results in the same table indicate that the highest level of nickel of 38150 µg/g was found in the root of *Cynanchum tubulosum* (L. F.) Engl., while the lowest level of nickel of 420 µg/g was found in the shoot of *Cynodon dactylon* (L.) Pers.

Table 3. Levels of lead, zinc, cadmium and nickel in soils and plant roots and shoots around the tailing dam of North Mara gold mine

Plant species	Lead (µg/g)			Zinc (µg/g)			Cadmium (µg/g)			Nickel (µg/g)		
	Soil	Root	Shoot	Soil	Root	Shoot	Soil	Root	Shoot	Soil	Root	Shoot
Indigofera cuneata Bak.	402	1337	306	111	37	38	10	20	57	1020	1552	957
Eragrostis aethiopica Chiov.	402	857	857	111	1812	135	10	762	160	1020	7700	1617
Acacia albida Bentha.	400	549	319	110	44	62	9	34	51	1019	750	892
Euphorbia hirta L.	250	18100	12925	61	1150	250	8	1100	50	740	32500	13225
Hibiscus nicranthus L.	252	1340	1240	63	75	95	9	40	150	740	1727.5	1772
Gomphrena celosioides L.	252	557	27950	63	50	1050	9	47	600	740	1800	26500
Grewia microcarpa K. Schum.	502	180	122	142	24	47	12	5	18	909	651	788
Cynodon dactylon (L.) Pers.	502	384	527	142	99	162	12	15	17	909	542	420
Aerva lanata (L.) Schultes.	502	233	315	142	37	50	12	24	9	909	646	746
Sporobolus pyramidalis P. Beauv.	502	450	231	142	127	128	12	57	17	909	1605	638
Cynachum tubulosum (L. F.) Engl.	334	20250	2110	101	2000	135	11	900	10	655	38150	3365
Setaria incrassata (Hochst.) Hack.	334	402	310	101	52	39	11	64	30	655	729	539

The results in Table 4 show the bioaccumulation and translocation factors of the heavy metals in the studied plant species. BAF and TF that were above 1 are in bold font. *Indigofera cuneata* Bak., *Eragrostis aethiopica* Chiov., *Acacia albida* Bentha., *Euphorbia hirta* L., *Hibiscus nicranthus* L., *Gomphrena celosioides* L., *Cynanchum tubulosum* (L. F.) Engl. and *Setaria incrassata* (Hochst) Hack. had BAF > 1 for lead. *Eragrostis aethiopica* Chiov., *Euphorbia hirta* L., *Hibiscus nicranthus* L. and *Cynanchum tubulosum* (L. F.) Engl. had BAF > 1 for zinc.

Furthermore, *Indigofera cuneata* Bak., *Eragrostis aethiopica* Chiov., *Acacia albida* Bentha., *Euphorbia hirta* L., *Hibiscus nicranthus* L., *Gomphrena celosioides* L., *Cynodon dactylon* (L.) Pers., *Aerva lanata* (L.) Schultes., *Sporobolus pyramidalis* P. Beauv., *Cynanchum tubulosum* (L. F.) Engl. and *Setaria incrassata* (Hochst.) Hack. had BAF > 1 for cadmium. *Indigofera cuneata* Bak., *Eragrostis aethiopica* Chiov., *Euphorbia hirta* L., *Hibiscus nicranthus* L., *Gomphrena celosioides* L., *Sporobolus pyramidalis* P. Beauv., *Cynanchum tubulosum* (L. F.) Engl. and *Setaria incrassata* (Hochst.) Hack. had BAF > 1 for nickel (Table 4).

On the contrary, *Gomphrena celosioides* L., *Cynodon dactylon* (L.) Pers. and *Aerva lanata* (L.) Schultes. had TF > 1 for lead. *Indigofera cuneata* Bak., *Acacia albida* Bentha., *Hibiscus nicranthus* L., *Gomphrena celosioides* L., *Grewia microcarpa* K. Schum. , *Cynodon dactylon* (L) Pers., *Aerva lanata* (L.) Schultes. had TF > 1 for zinc (Table 4).

Also, *Indigofera cuneata* Bak., *Acacia albida* Bentha., *Hibiscus nicranthus* L., *Gomphrena celosioides* L., *Grewia microcarpa* K. Schum. and *Cynodon dactylon* (L.) Pers. had TF > 1 for cadmium. *Acacia albida* Bentha., *Hibiscus nicranthus* L., *Gomphrena celosioides* L., *Grewia microcarpa* K. Schum. and *Aerva lanata* (L.) Schultes. had TF > 1 for nickel (Table 4).

Table 4. Bioaccumulation and Translocation Factors of heavy metals in the studied plant species

Plant species	Lead		Zinc		Cadmium		Nickel	
	BAF	TF	BAF	TF	BAF	TF	BAF	TF
Indigofera cuneata Bak.	**3.3**	0.22	0.3	**1.01**	**2.0**	**2.85**	**1.5**	0.61
Eragrostis aethiopica Chiov.	**2.1**	1	**16.3**	0.07	**76.2**	0.20	**7.5**	0.21
Acacia albida Bentha.	**1.4**	0.58	0.4	**1.40**	**3.8**	**1.5**	0.7	**1.19**
Euphorbia hirta L.	**72.4**	0.71	**18.9**	0.21	**137.5**	0.04	**43.9**	0.41
Hibiscus nicranthus L.	**5.3**	0.92	**1.2**	**1.26**	**4.4**	**3.75**	**2.3**	**1.03**
Gomphrena celosioides L.	**2.2**	**50.13**	0.8	**21**	**5.2**	**12.6**	**2.4**	**14.7**
Grewia microcarpa K. Schum.	0.4	0.67	0.2	**1.95**	0.4	**3.6**	0.7	**1.21**
Cynodon dactylon (L.) Pers.	0.8	**1.37**	0.7	**1.63**	**1.3**	**1.13**	0.6	0.77
Aerva lanata (L.) Schultes.	0.5	**1.35**	0.3	**1.35**	**2.0**	0.37	0.7	**1.16**
Sporobolus pyramidalis P. Beauv.	0.9	0.513	0.9	1.00	**4.8**	0.29	**1.8**	0.39
Cynanchum tubulosum (L. F.) Engl.	**60.6**	0.10	**19.8**	0.06	**81.8**	0.01	**58.2**	0.09
Setaria incrassata (Hochst.) Hack.	**1.2**	0.77	0.5	0.75	**5.8**	0.46	**1.1**	0.739

4. DISCUSSION

The studied heavy metals; Pb, Zn, Cd and Ni had both BAF and TF > 1 in some species. This suggests that these plant species were effectively accumulating and subsequently transferring heavy metals to the aerial parts. These plant species which could be used to extract the studied heavy metals from soils, with the metals in bracket were *Gomphrena celosioides* L. (Pb, Cd and Ni), *Hibiscus nicranthus* L. (Zn, Cd and Ni), *Indigofera cuneata* Bak. (Cd), *Acacia albida* Bentha. (Cd) and *Cynodon dactylon* (L.) Pers. (Cd). A key feature of metal accumulation is the efficient metal transport from roots to shoots, characterized by the translocation factor being greater than one [39]. In Nigeria, [40] identified *Gomphrena celosioides* as one of the plant species that are capable of accumulating cadmium.

On the other hand, some plant species accumulated heavy metals in their roots thereby limiting transference to the aerial parts. These species with the metal(s) in brackets included, *Indigofera cuneata* Bak. (Pb and Ni), *Eragrostis aethiopica* Chiov. (Zn, Cd and Ni), *Euphorbia hirta* L. (Pb, Zn, Cd and Ni), *Hibiscus nicranthus* L. (Pb and Ni), *Gomphrena celosioides* L. (Ni), *Sporobolus pyramidalis* P. Beauv. (Cd and Ni), *Cynanchum tubulosum* (L. F.) Engl. (Pb, Zn, Cd and Ni), *Setaria incrassata* (Hochst.) Hack. (Pb, Cd and Ni), *Aerva lanata* (L.) Schultes. (Cd) and *Acacia albida* Bentha. (Pb). According to [18], these species are likely using exclusion mechanisms to tolerate heavy metal stress. Plant species which limit heavy metal translocation to the aerial parts do so by altering membrane permeability, changing metal binding capacity of cell walls or by exuding more chelating substances [41]. However, an appropriate plant for phytoremediation should have high translocation factor of heavy metals into the shoot [42, 39]. At genus level; *Euphorbia cyparissias* has been reported to accumulate higher levels of zinc in the zinc mine tailing in Poland [43]. Zinc accumulation was also reported at Keban mining by using *Euphorbia macroclada* in Elazig, Turkey [44]. Also, [45] reported that *Euphorbia cheiradenia* as one of the plant species capable of accumulating very high levels of lead, nickel and zinc in Iran.

The process of extracting toxic metals from soils and accumulating them generally requires the translocation of heavy metals to the easily harvestable plant parts. Plants with translocation and bioaccumulation values of less than one suggest that they are unsuitable for extracting heavy metals from soils [14].

5. CONCLUSION

Of the plant species that were growing around the tailing dam, *Gomphrena celosioides* L., *Hibiscus nicranthus* L., *Indigofera cuneata* Bak., *Acacia albida* Bentha. and *Cynodon dactylon* (L.) Pers. were considered as the most promising species for extraction of Pb, Zn, Cd and Ni -contaminated areas in North Mara gold mine by having the highest potential for bioaccumulation and subsequent translocation. There is a need to explore more plant species which highly accumulate heavy metals in metal-mining areas and investigation of their applicability. This is because, according to [46], heavy metal accumulation varies depending on the climatic conditions, soil characteristics and other factors.

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