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Phytoremediation of Potential Toxic Elements by Tree Species in Abandoned Mining Sites

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Abstract: Toxic elements such as heavy metals are left behind after the completion of mining operation and being non bio-degradable, these contaminate the soil and water ecosystem for generations. This research work evaluated the phyto extracting ability for potential toxic elements by eleven (11) tree species that are predominantly growing in an abandoned mining spoil sites in Mogpog, Marinduque, Philippines. Plant and soil samples were collected in the field and analyzed using ICP-OES. The soil was highly contaminated with heavy metals, largely copper (Cu), manganese (Mn) and Iron (Fe) which is twenty times to fifty times more than the typical non-contaminated Philippine soil. Among the trees evaluated, Antidesma ghaesembilla showed the highest potential for Cu and Mn denromediation, having a bioconcentration factor (BCF) of 1.51 and 2.2, respectively. This tree species had high level of Cu and Mn per dry wt. in plant tissues. Other tree species that showed promising potential as phytoremediators for Cu and Mn contaminated soils were Alstonia scholaris, Eucalyptus camaldulensis, and Pterocarpus indicus. Alstonia scholaris gave the highest potential as phytoextractor for Ni and Fe toxic soils. None of the tree species was found to be hyperaccumulator for Cu, Ni, Cr, Mn and Zn.

Key words: phytoextraction, dendroremediation, bioconcentration factor (BCF), heavy metals

1. Introduction

Mining produces a lot of pollutants in the form of potentially toxic elements, e.g., heavy metals that contaminates the soil and water ecosystems. Potentially toxic elements are generally non-biodegradable and difficult to manage due to their mobility in soil and water environment. Increased concentrations of potentially toxic elements in the soils and water generally result in phytotoxicity in plant and animal, directly threatening human health and can have exacerbated effects when these enter the food chain as ground and surface water contaminants [1]. Several physiological and biochemical processes in plants can be severely affected by these metals, however, their toxicity varies with plant species, and the chemical form and concentration of the element [2].

Traditional methods of removing toxic elements in water and soil are generally very expensive and less successful [3-5]. Excavation of mining wastes and disposing them to landfills do not alleviate its hazards. The pollution problem is simply relocated in space and time [6]. Being prohibitively expensive, most of the mining companies ignore the problem, abandoning the site after the operation ceases.

One of the methods in cleaning in abandoned mining sites is the use of phytoremediation. As a phytotechnology, it uses plants in cleaning up of contaminated sites [3, 7]. The plant helps in the removal, reduction, immobilization and degradation of heavy metals in the soil [8]. Some of the plants can accumulate the metals in stem, shoot and leaves, other can produce enzymes, such as dehalogenase and oxygenase that can degrade the elements in their tissues while some can stabilize the metal through immobilization at the interface of roots and soil [9].

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Plant species that are commonly used in the bioremediation are called hyperaccumulator. These group of plants are capable of accumulating and tolerating considerable level of heavy metals. The heavy metals are absorbed from the soil, then translocated and accumulated in plant biomass [10].

Using plants to clean up the environment is applicable in the restoration of contaminated soils and water and it was found to be an effective technology in reclaiming contaminated areas because of its cost effectiveness, aesthetic advantage and long term applicability to wide range of toxic elements [11, 12].

Plants suitable for successful phytoextraction of heavy metals should be tolerant to high concentration of metals and at the same time, be able to accumulate of essential and non-essential metals in plant organs. *Pteris vittata*, a fern species is found to be a hyper accumulator of arsenic [13]. For phytoremediation of Pb and Zn, *Brassica juncea* has the greatest potential [14, 15].

Use of trees known as dendroremediation is recommended in removing contaminations not only in abandoned mining areas but also in industrial areas for conversion to residential communities. The use of trees as phytoremediator have many advantages as compared to small plant species like shrubs, grasses and ferns. They are fast growing and produce relatively large volume of harvestable biomass. The use of trees is cheaper and more environmentally acceptable technology compared to traditional methods [16].

The most commonly used flora in phytoremediation projects in Europe were poplar trees, primarily because these trees are fast growing and can survive in broad range of climatic and soil conditions. In addition, poplar trees can draw large amounts of water (relative to other plant species) as it passes through soil or directly from aquifer [11, 17]. This may uptake greater amounts of dissolved pollutants from contaminated media and reduce the amount of water that may pass through soil or aquifer, thereby reducing the amount of contaminant percolating into aquifer.

The advantageous effect of poplar on soil and underwater has also been widely studied. Their secret lies in the naturally well designed root system which take up large quantities of water. A tree species, *Betula alnoides* is highly suggested species for the reforestation of mining sites with high levels of Pb and Zn [18]. Another successful used of phytoremediation technology is in Sweden. Willows (*Salix viminalis*) is tree species cultivated for the phytoextraction of Cd and Zn and at apparently for bio-energy production [19]. They stated that around 15,000 ha were planted by willows in Sweden for this purpose.

Trees varies in their ability to grow in highly contaminated soil. Selection of species as phytoremediator is an important aspect for the practical use of this technology because most plant hyperaccumulators have slow biomass production and slow growing [20]. The most ideal species are those plant species growing in mine tailing areas as they have evolved sophisticated adaption mechanisms to tolerate potentially toxic levels of metals in the soil [21]. Local or endemic species are desirable since these are already adapted to local conditions and just need the ability to survive in harsh environment of heavy metals. Moreover, sources for mass propagation are accessible and readily available.

This field research activity was conducted to determine the phytoextracting ability of tree species growing in heavy metal contaminated soils in an abandoned mining site in Marinduque, Philippines.

2. Material and Methods

2.1 The Research Area

This research work was conducted in the abandoned copper mine site previously operated by Consolidated Mining Corporation located in Barangay Capayang, Mogpog, Marinduque, Philippines (Fig. 1). The abandoned mine site covered 1259.32 ha of open pit type of mining [22]. The mining operation ceased in 1996. The open-pit in the area is now filled with toxic water and has become a major source of irrigation for the adjacent ice farms. Although patches of shrubs, grasses, ferns and trees flourish in the surrounding area, significant portion of the exposed pile of copper-contaminated soil has limited vegetation cover. The mining dump site serve as source of heavy metals and poses danger to the surrounding mangrove areas, rice farms and resident communities. Phytoremediation activities is needed to lessen the mobility of heavy metals and to protect to the rice farms and marine environments.

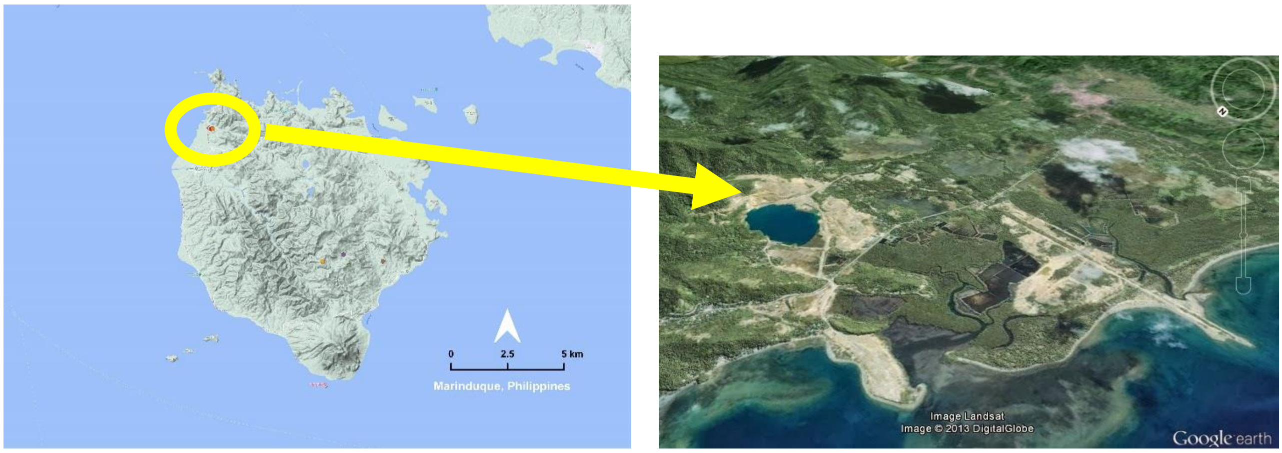

Fig. 1 Aerial view and dump sites of Consolidated Mining Corporation (CMI) mining that operated in Marinduque, Philippines from 1969 to 1996.

2.2 Soil Sampling and Analysis

Soil samples were collected in four (4) sampling points along the main dump sites (Fig. 1). In each sampling points three (3) subsample surface soils were collected using soil auger from 0-30 cm depth. Soils were mixed thoroughly in each sampling point to make composite samples. A 1 kg composite sample from each sampling point was taken, air dried, sieved. A 200 g soil sample from each sampling point was brought for laboratory analysis in Soil Chemistry Department, University of the Philippines at Los Baños, Laguna, Philippines. Soil samples were digested with $HN0_3$ and H_2O_2 [23, 24]. Concentrations of potential toxic elements in soils were analyzed using ICP-OES [23].

2.3 Plant Sampling and Analysis

Samples of tree species were collected near the soil sampling points. Eleven (11) tree species identified in the area were assessed in this study. A total of 47 plant samples were collected. Three to seven whole plant sample of trees with height two feet and below were collected in this work. The tree species were summarized in Table 2. Samples were washed initially with tap water and later with distilled water to remove soil contaminants. The samples were air dried for one week and cut into 1 cm pieces. Equal parts of roots, stems and leaves were thoroughly mixed and weighed. A 100 grams representative sample for each species were brought for laboratory analysis in Soil Chemistry Department, University of the Philippines at Los Baños, Laguna, Philippines. Extraction to determine the levels of potentially toxic elements were through wet ashing and digestion with nitric acid Concentrations of potential toxic elements were analyzed using ICP-OES [23].

2.4 Bio-concentration Factor (BCF)

The BCF (Bio-concentration Factor) value of all trees studied in this research were calculated. Bio-concentration Factor is a measure of ratio between the levels of heavy metals accumulated inside the plant over the level of heavy metals in the contaminated soil. It is an indicator of the ability of the plant to accumulate potential toxic elements with respect to the level of potential toxic elements in the substrate.

It was measured the BCF using the following formula [25]:

BF = Concentration of heavy metals in plant/ Concentration of heavy metals in soil

It is a good indicator to easily determine if the tree under observation can be classified as hyper accumulator, accumulators, and phytoexcluder in a given contaminated soil. Plant with bio-concentration factor greater than 10, as hyper accumulators, between 1 and 10 as accumulators, and with a value of less than 1 as excluders. It will also measure the phyto remediating capacity of plant species even at lower concentrations of toxic elements in soil environment.

3. Results

Based on the results of soil chemical analysis, the levels of Cu present in the contaminated soil was 309.77 mg kg^{-1} dry wt. of Cu. The soil also contains a mean value of 225 mg kg^{-1} dry wt. of Mn, 104.77 mg kg^{-1} dry wt. of Zn, 42.71 mg kg^{-1} dry wt. of Ni and 78.63 mg kg^{-1} dry wt. of Cr. The concentration levels of Fe is very high (12,300 mg kg^{-1} dry wt.) which is typical to tropical soils. The mine spoil soils is very acidic with a pH range of 3.3 to 4.1.

3.1 Tree Species in the Mining Site

Eleven (11) tree species were identified commonly growing in the abandoned mining sites (Table 2).

Eight (8) species were endemic in the Philippines while the 3 other species were introduced in the area. The 8 endemic species were *Vitex parviflora, Alstonia macrophylla*, *Antidesma ghaesembilla*, *Leucaena leucocephala*, *Trema orientalis*, *Pterocarpus indicus*, *Alstonia scholaris*, and *Psidium guajava*. The other three exotic species were introduced from Australia to the Philippines. These are *Eucalyptus camaldulensis*, *Acacia mangium*, and *Acacia auriculiformis*.

Table 1 Concentrations of potential toxic elements present in soil samples in abandoned mining site.

Element	Range of Concentration of Potential Toxic Elements (mg kg^{-1} dry wt.)	Mean (mg kg^{-1} dry wt.)
Cu (mg kg^{-1} dry wt.)	225.33-368.83	309.79
Zn (mg kg^{-1} dry wt.)	62.66-165.95	104.77
Mn (mg kg^{-1} dry wt.)	124.3-425.7	225.34
Cr (mg kg^{-1} dry wt.)	42.67-123.25	78.63
Ni (mg kg^{-1} dry wt.)	23.54-61.87	42.71
Fe (mg kg^{-1} dry wt.)	10400-15700	12300

Table 2 Species of trees sampled and identified in the abandoned mining sites in Capayang, Mogpog, Mariduque Philippines.

Tree Species	**Family**	**Classification**
Vitex parviflora	Lamiaceae/Verbenaceae	Endemic
Alstonia macrophylla	Apocynaceae	Endemic
Antidesma ghaesembilla	Phyllanthaceae	Endemic
Leucaena leucocephala	Fabaceae	Endemic
Acacia auriculiformis	Mimosaceae	Exotic
Trema orientalis	Cannabaceae/Ulmaceae	Endemic
Pterocarpus indicus	Fabaceae	Endemic
Alstonia scholaris	Apocynaceae	Endemic
Eucalyptus camaldulensis	Myrtaceae	Exotic
Acacia mangium	Mimosaceae	Exotic
Psidium guajava	Myrtaceae	Endemic

3.2 Phyto-extracting Ability of Trees

The phytoextracting potential of tree species were evaluated by analyzing the plant tissues using ICP-OES. Levels of Cu present in tree biomass were shown in Fig. 2. The levels of copper present in trees ranges from 55.44 mg kg^{-1} dry wt found in *Leucaena leucocephala* to 466.98 mg kg^{-1} dry wt. observed in *Antidesma ghaemsembilla*. The other tree species that absorbed high levels of Cu were *Eucalyptus camaldulensis, Pterocarpus indicus, Alstonia scholaris* and *Trema orientalis.* The result values were 360.52 mg kg^{-1} dry wt., 270.75 mg kg^{-1} dry wt., 245.54 mg kg^{-1} dry wt, 219.56 mg kg^{-1} dry wt. of Cu in their biomass, respectively.

The levels of Mn present in tree biomass were presented in Fig. 3. The tree species that absorbed high amount of Mn were *Eucalyptus camaldulensis*, *Alstonia scholaris*, *Pterocarpus indicus* and *Trema orientalis.* The observed value were 496 mg kg^{-1} dry wt, 382.13 mg kg^{-1} dry wt, 315.97 mg kg^{-1} dry wt, 287.30 mg kg^{-1} dry wt, and 215. 21 mg kg^{-1} dry wt of Mn in their biomass. Lowest absorbed value for Mn were obtained from plant tissues of *Leucaena leucocephala* with a value of 56.00 mg kg^{-1} dry wt of Mn.

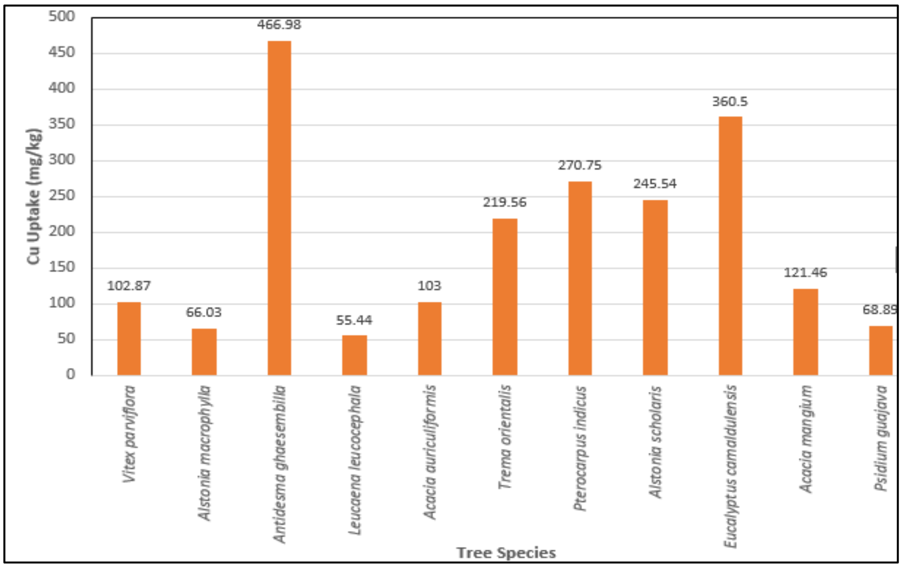

Fig. 2 Levels of Cu in different tree species.

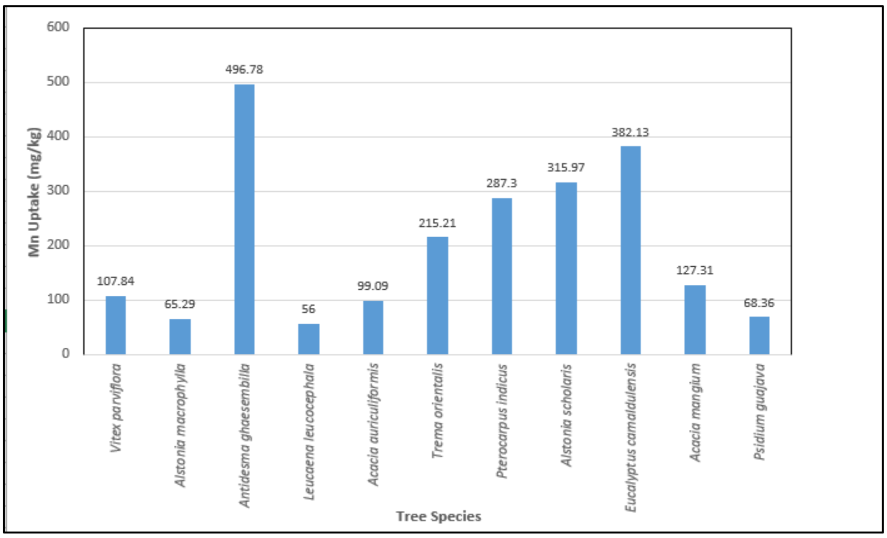

Fig. 3 Levels of Mn in different tree species.

Alstonia scholaris gave the highest response in absorption of Nickel (Fig. 4). The observed value were 242.53 mg kg^{-1} of Ni. Other tree species showed lower absorption levels of Ni in their plant tissues.

The levels of Zn present in tree biomass were presented in Fig. 5. The tree species that contains high level of Zn in the biomass were *Pterocarpus indicus and Eucalyptus camaldulensis* gave the highest response for absorption of Zn with a value of 50.86 mg kg^{-1}dry weight and 49.17 mg kg^{-1}dry weight. These values were considered low compared to other known plant hyperaccumulators of Zn.

The levels of Cr present in tree biomass were presented in Fig. 6. The tree species that contains high level of Cr in the biomass were *Pterocarpus indicus, Eucalyptus camaldulensis, Alstonia macrophylla, Leucaena leucocephala* and *Antidesma ghaesembilla.* The observed value were 75.64 mg kg^{-1} dry wt, 75.17 mg kg^{-1} dry wt, 62.69 mg kg^{-1} dry wt, 61.44 mg kg^{-1} dry wt, and 52.96 mg kg^{-1} dry wt of Mn in their biomass.

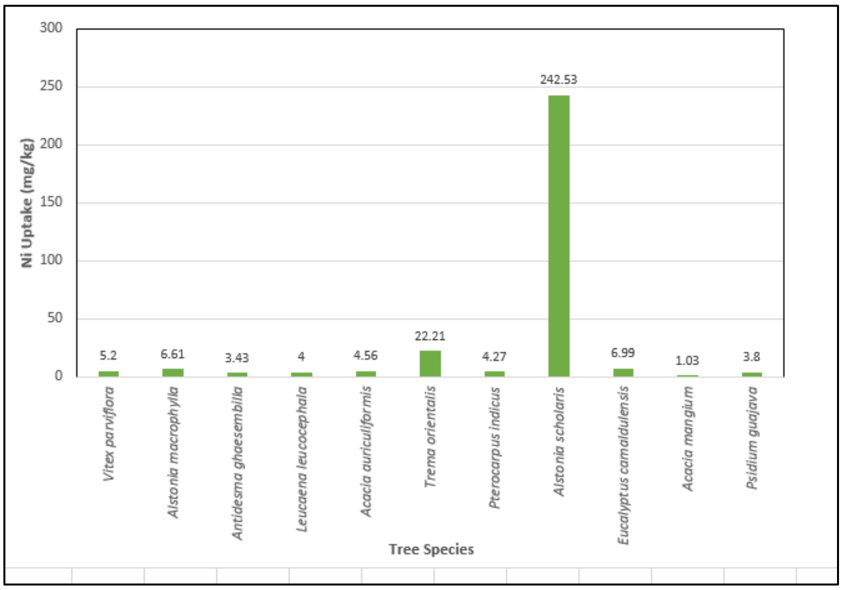

Fig. 4 Levels of Ni in different tree species.

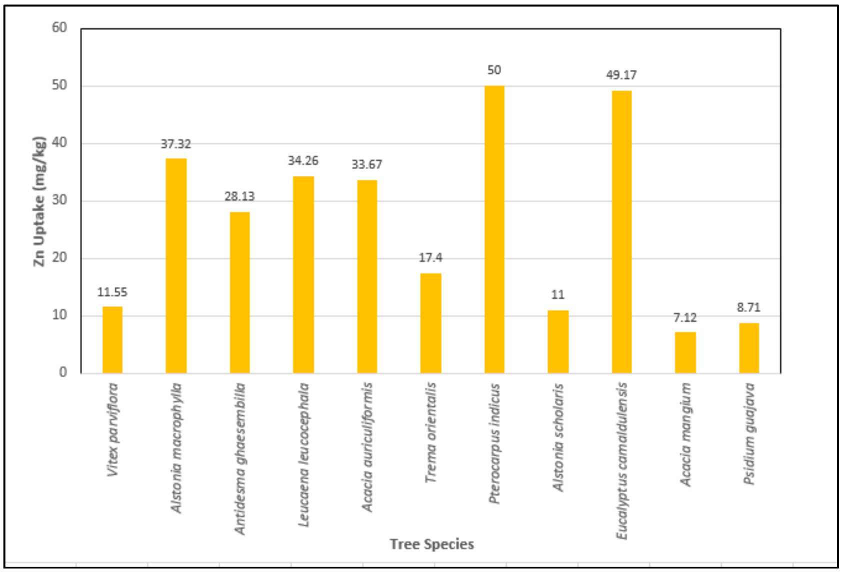

Fig. 5 Levels of Zn in different tree species.

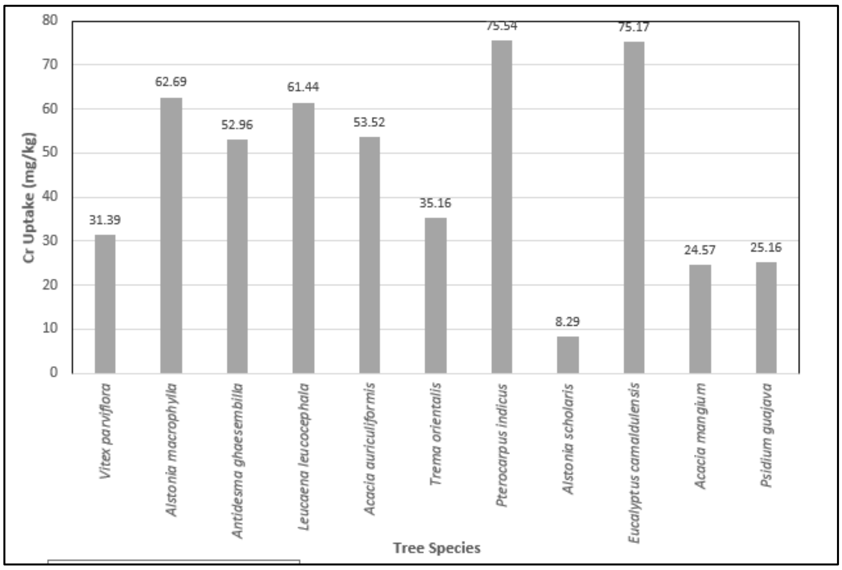

Fig. 6 Levels of Cr in tree species.

Fe uptake of trees were presented in Fig. 7. Highest observed value were obtained from *Alstonia scholaris* with a value of 43,009.09 mg kg^{-1} dry wt of Fe. It was followed by *Acacia auriculiformis*, *Acacia mangium*, and *Trema orientalis.* The observed value were 2715.41 mg kg^{-1} dry wt, 514.39 mg kg^{-1} dry wt and 507.21 mg kg^{-1} dry wt of Fe, respectively. Although Fe is not considered as a heavy metal, elevated levels of Fe in soil could be toxic since it has negative effects in increasing soil pH [26].

3.6 Bioconcentration Factor (BCF)

Bioconcentration factor is a measure of how much potential toxic elements accumulated by each tree species based on the concentration of heavy metals present in the contaminated soil. Based on results of calculated bioconcentration factor, for Cu highest BCF were observed from *Antidesma ghaesembilla* and *Eucalyptus camaldulensis* with a value of 1.51 and 1.17. Other tree species gave a BCF less than 1.0. For Mn, tree species that have a BCF value greater than 1.0 were observed from *Antidesma ghaesembilla*, *Alstonia scholaris, Pterocarpus indicus* and *Eucalyptus camaldulensis* with a value of 2.2, 1.4, 1.27 and 1.25, respectively. Majority of observed value for BCF of Zn is > 1.0. This could be attributed to low Zn concentration in the soil. BCF value for Cr were > 1.0. Highest Cr absorption was observed in *Pterocarpus indicus* and *Eucalyptus camaldulensis* with a value of 0.96 and 0.95. Highest Ni uptake with highest BCF was observed from *Alstonia scholaris* with a value of 5.67. The BCF value for Fe were all >1.0 except in *Alstonia scholaris* that demonstrated the highest BCF for Fe with a value of 3.49.

4. Discussion

The concentration of Cu present in the mining site spoil soil is quite high (309.79 mg kg^{-1} dry wt.) compared to normal Philippine soils with copper levels which ranges from 5.2 to 30 ppm [27]. The level of copper is 20 to 50 times higher than in normal soil. This observed value is much lower than the result reported by another study in the area which observed that the level of copper in the mining area could be as high as 2520 mg kg^{-1}dry wt using AAS analysis [28]. High Cu concentrations is attributed to mine spoiled soils dumped in the area as a result of more than 25 years of mining.

The soil also contains 225.34 mg kg^{-1} dry wt. of Mn, 78.63 mg kg^{-1} of Cr, 42.71 mg kg^{-1} dry wt of Ni and 12,300 mg kg^{-1} dry wt. of Fe (1.23%). The elevated contents of Cu, Mn, and Fe are considered toxic based on the normal requirements of plants [26]. Levels of Cr, Zn, and Ni in the mine spoiled soils are not elevated to be considered toxic to plants. However, the presence of these elements can also be bioaccumulated by trees through time in as these trees continually grow in the area. A similar study conducted in Calancan Bay, Marinduque Island, Philippines. They observed lower concentarions of Cu, Zn and Pb. Their results were 24.77 mg kg^{-1} dry wt Cu, 6.55 mg kg^{-1} dry wt Zn and 4.05 mg kg^{-1} dry wt Pb, respectively [29]. A sediment analysis of mine tailings conducted in marine sediments along the seashore of Boac River, in Marinduque, where Marcopper Mining disaster happened. Results found out that the sediments contain 706-3080 mg kg^{-1} dry wt of Cu, 445-1060 mg kg^{-1} dry wt of Mn, 43-56 mg kg^{-1} dry wt of Pb and 131-176 mg kg^{-1} dry wt. of Zn [30].

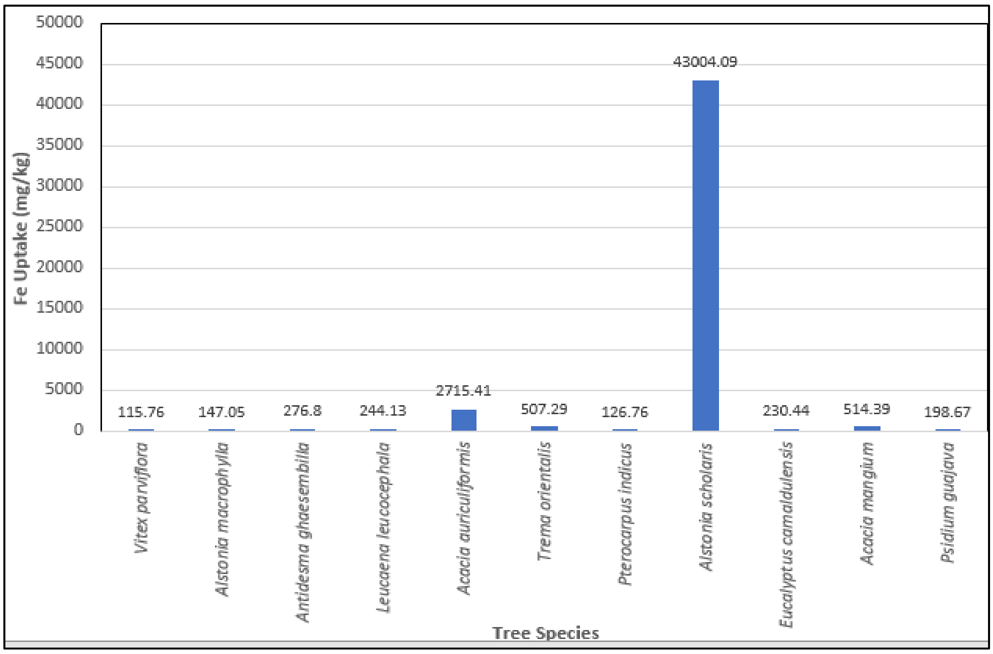

Fig. 7 Levels of Fe in tree species.

Table 3 Bioconcentration Factor (BCF) of different tree species for the uptake of Cu, Mn, Zn, Cr, Ni, and Fe.

Tree Species	Cu	Mn	Zn	Cr	Ni	Fe
Vitex parviflora	0.33	0.48	0.11	0.39	0.12	0.01
Alstonia macrophylla	0.21	0.29	0.35	0.79	0.15	0.01
Antidesma ghaemsembilla	**1.51**	**2.20**	0.27	0.67	0.08	0.02
Leucaena leucocephala	0.18	0.25	0.32	0.78	0.11	0.20
Acacia auriculiformis	0.33	0.49	0.32	0.68	0.10	0.22
Trema orientalis	0.71	0.95	0.16	0.44	0.52	0.04
Pterocarpus indicus	0.88	**1.27**	0.48	**0.96**	0.10	0.10
Alstonia scholaris	0.79	**1.40**	0.10	0.10	**5.67**	**3.49**
Eucalyptus camaldulensis	**1.17**	**1.25**	0.46	**0.95**	0.16	0.18
Acacia mangium	0.39	0.56	0.07	0.31	0.04	0.04
Psidium guajava	0.22	0.30	0.08	0.33	0.09	0.16

Soil samples analyzed for heavy metals in a contaminated area in El Paso, Texas, USA have higher levels of heavy metals. The soil contains 5,067 mg kg^{-1} dry wt Pb and 4,993 mg kg^{-1} dry wt Cu [31].

Successful phytoextraction program in restoring soils polluted by heavy metals can be achieved by the selection of the most suitable plant species for specific potential elements [16]. Most of the tree species evaluated in the copper contaminated sites were considered as pioneer tree species. It means their survival rates in harsh and toxic soil environment is higher compared to common tree species. None of the tree species were able to absorbed above the 1000 mg kg^{-1} dry wt for Cu, Ni, and Cr. level to classify them as phyto accumulator of Cu, Cr and Ni [32]. The result also does not met the requirements to be hyperaccumulator for Zn and Mn which requires above 10,000 mg kg^{-1} dry wt. Among the heavy metal evaluated, copper, iron, manganese and zinc were considered as important microelement in tree nutrition while nickel and chromium are not classified as nonessential microelement.

Result showed that all these trees can uptake more than 30 mg kg^{-1} Cu which is above the normal requirement for Cu in plants which ranges from 5 to 30 mg kg^{-1} dry wt [26].

The tree species which have the highest potential as phyto extractor for Cu contaminated sites based on this esearch work were *Antidesma ghaemsembilla and Eucalyptus camaldulensis.* These trees also gave bioaccumulation factor >1.0 and could be classified as potential phytoextractor of Cu. The result is considered significant because these trees were able to demonstrate some degree of tolerance to high levels of Cu present in the soil. *Antidesma ghaemsembilla,* with common name “binayuyu” in the Philippines is a native tree species. It is a medium sized tree and produced hard wood timber for local construction. *Eucalyptus camaldulensis* is a non- native tree species introduced from Australia. This tree species is known for its high tolerance to aluminum toxicity [33]. In another pot experiment conducted, *E. camaldulensis* can absorb high amounts of Cu and Zn [34].

In a pot experiment using Cu contaminated soils collected in the same area, results reported that *Vitex parviflora*, *Samanea saman*, and *Pongamia pinnata* showed higher level of 1776 mg kg^{-1}, 953 mg kg^{-1}, 1219 mg kg^{-1} of Cu in their root tissues [28]. *Vitex parviflora* in this study absorb a much lower level of Cu (102.7 mg kg^{-1}). This showed great discrepancies in result between pot experiment and actual field data. Environmental factors like limited soil moisture and extreme hot temperature in the mining area have great influence in phytoextracting ability of tree species and mobility of heavy metals. *Larrea tridentata,* creosote bush species, growing around a heavy metal contaminated area in Texas, USA was able to absorb and stored in its roots, stems, and leaves of 953 mg kg^{-1}, 493 mg kg^{-1} and 370 mg $kg^{-1}$of copper, respectively [31].

The tree species which have the highest potential as phyto extractor for Mn contaminated sites based on this study were *Antidesma ghaesembilla, Alstonia scholaris, Eucalyptus camaldulensis, and Pterocarpus indicus.* These tree species have accumulated and can tolerate more than 300 mg kg^{-1} dry wt of Mn inside their tissues. The normal concentration for Mn in plants ranges from 20 to 300 mg kg^{-1} dry wt [26]. These trees are fast growing species can absorb substantial amount of Mn (BCF > 1.0) inside their plant tissues that will reduce substantial amount of Mn retain in the soil. Among the native tree species evaluated, *Pterocarpus indicus* has the highest potential to produce large amount of biomass. This tree also has high economic value.

The tree species bioaccumulated Zn within range of normal levels to plants. Although the level of Zn is not consideredtoxic in these soils (104.77 mg kg^{-1} dry wt Zn), the trees were able to absorb between 8.29 mg kg^{-1} dry wt of Zn up to 75.64 mg kg^{-1} dry wt of Zn. This is still within the normal range for Zn requirement in trees which is around 15-20 mg kg^{-1} dry wt. [26]. *Eucalyptus camaldulensis* and *Pterocarpus indicus* are the two tree species that have shown to have high potential as phytoextractors of Zn. *Eucalyptus camaldulensis* can absorb 253.0 mg kg^{-1} dry wt. of Zn [34]. The high result is attributed to higher Zn content used in their experiment. The results for Zn absorption is much lower compared to known Zn hyperaccumulators like *Thlaspi caerulescens* [32].

Fe in tree tissues were as low as 126.78 mg kg^{-1} dry wt in *Pterocarpus indicus* to as high 43,004.09 in mg kg^{-1} dry wt of Fe in *Alstonia scholaris*. Although the normal range for Fe is 100 to 500 mg kg^{-1} dry wt, results showed that *Alstonia scholaris* is the tree species that has the highest tolerance to Fe toxic soils. Other trees that showed tolerance to Fe toxic soils were *Acacia auriculiforms* and *Acacia mangium*. These two tree species have known associations with mycorrhiza that can increase its Fe tolerance in toxic soils. Fe toxicity in plants is of lesser important compared to Pb, Cd, As and Uranium [35].

Chromium and Nickel are two elements that have limited importance in tree nutrition [26]. *Eucalyptus camaldulensis and Pterocarpus indicus* absorbed the highest level of Cr inside its tissues among the trees evaluated. These two tree species have higher affinity to Cr but their capacity to absorb Cr cannot be considerd as hyperaccumulators [32]. Other plant species that absorb high levels of Cr based on study conduted in Hungary were Reed (*Phragmatis australis*), Bulrush (*Typha angustifolia*), and Orach (*Atriplex hastrata*), [36].

Alstonia scholaris also gave the highest bioaccumulation level for nickel among tree species evaluated with a value of 5.67. It means this tree species can absorb five times more Ni present in the soil. The result is much lower compared to the phytoaccumulator of Ni (*Rinorea niccolifera*) which is growing in serpentine mining sites in Zambales, Luzon, Philippines. This shrub species can bioaccumulate up to 18,000 mg kg^{-1} dry wt of nickel [37]. However, this shrub species is slow growing and produced less above ground biomass compared to *Alstonia scholaris*, which is a relatively fast growing tree species. Metal uptake of trees is reported to be small compared to known plant hyperaccumulators but on a per hectare scale, the capacity of trees to remove heavy metals could be more effective due to greater biomass yield [19].

Some plants can bioaccumulate higher concentrations of potential toxic elements but they do not produce large enough biomass compared to trees. Metal uptake of trees is reported to be small compared to known plant hyperaccumulators but on a per hectare scale, the capacity of trees to remove heavy metals could be more effective due to greater biomass yield. *Salix viminalis*, a well-studied phytoremediator tree species in Europe was able to accumulate higher level of Cd and Zn on a per hectare basis compared to *Thlaspi caerulescens*, a known hyperaccumulator of these elements [19].

Ferns have been reported to have higher affinity to bioaccumulate different types of heavy metals. *Onychium silicosum*, a native fern growing in the same area, demonstrated the most promising results as hyper accumulator of Cu. It can absorb up to 2006.22 mg kg^{-1} dry wt of Cu in its biomass [38]. However, this fern species also produce not enough biomass and have low economic potential to be considered as potential phytoextractor.

Poplar (*Populus alba* L.), willows (*Salix viminalis* L.) and Black locusts (*Robinia pseudoacacia*) are common tree species that are used for phytoremediation with high economic value. Willow trees also have high coppicing ability and short rotation cycles that is advantageous trait for phytoextraction [11]. The phytoextracting ability of *Populus alba* for As, Cd, Cu and Pb were investigated. Result showed that there is higher metal content in roots than in shoots [39]. *Betula alnoides*, a reforestation tree species in Southern China is good phytoremediator for Pb among the six tree species they evaluated in a pot experiment [40].

Metal uptake of trees is not as high as metallophytes but due to its great yield biomass, the removal of metals from the soil could be more effective with respect to hyperaccumulating plants [42]. The use of trees rather than small phytoaccumulator plant species have many advantages. Trees have long term ecological values because trees can remain healthy for many years even growing in highly contaminated soils. Trees can be planted and mixed with high absorbing plant species [42]. Trees can be grown along with other plant hyperaccumulators. These will increase the biodiversity in the rehabilitation area damaged by mining activities.

Trees produce more woody biomass for energy production. It is more cleaner, cheaper, and more environmentally acceptable approach to dendrothermal energy production than coal and fossil fuel [16, 19]. Most trees can tolerate low fertile soils with impaired hydrological properties and can withstand harsh environmental conditions prevailing in the abandoned mine spoil soils. Lastly, trees absorbed greenhouse gases that has critical role in mitigating climate change.

5. Conclusion

Antidesma ghaemsembilla showed the highest potential tree species as a candidate tree phytoextractor for dendromediation of Cu and Mn contaminated soils. Other tree species that showed promising potential as phytoremediators for Mn and Cu contaminated soils were *Eucalyptus camaldulensis*, *Alstonia scholaris*, *Pterocarpus indicus* and *Trema orientalis*. *Eucalyptus camaldulensis* and *Pterocarpus indicus* have a high potential for phytoextraction of Cr and Zn. *Alstonia scholaris* demonstrated as the best species as phytoextractor for Ni and Fe toxic soils. None of the tree species demonstrated as hyperaccumulators since the absorbed value observed were not more than 1000 mg/kg dry wt. of Cu, Ni and Mn. Future pot experiments is needed to determine the growth rates of each plant species and their capacity to absorb other toxic elements remains to be investigated to determine their total capacity as phytoremediator in cleaning and restoration of abandoned mining sites.

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