The bioaccumulative potential of heavy metals in five forest species living in mining environments in the Ecuadorian Amazon region

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Abstract — **Heavy metal contamination of soils and ecosystems is an environmental problem that requires urgent attention due to the ecological problems that it generates. Forest species can be used to mitigate contamination because of their potential to bioaccumulate contaminating metals. The objective of this work was to evaluate the bioaccumulator potential of heavy metals in five forest species that live in mining environments in the Ecuadorian Amazon region. The bioconcentration factor for five forest species, such as: Cedrela odorata, Parkia multijuga, Inga edulis, Cecropia ficifolia and Pourouma cecropiifolia, commonly found in the Ecuadorian Amazon was analysed, based on the relationship between the concentration of the heavy metal in leaves and the soil. Atomic absorption spectrometry was used to analyse heavy metals in leaves and soil samples of each plant specie. The results showed that P. cecropiifolia had the highest bioconcentration factor for lead, C. odorata for cadmium and nickel, and I. edulis had the highest potential for iron and aluminium absorption. No correlation was found between the concentration of each element in the soil and the leaves, which shows that the bioaccumulation capacity of the species studied does not depend on the concentration of the element in the soil. This provides relevant information for the inclusion of these species for phytoremediation purposes.**

Keywords: **tree species; pollution; mining; leaves; soil; bioconcentration factor.**

Resumen — **La contaminación de suelos y ecosistemas por metales pesados es un problema ambiental que requiere atención urgente debido a los problemas ecológicos que genera. Las especies forestales se pueden utilizar para mitigar la contaminación debido a su potencial para bioacumular metales pesados. El objetivo de este trabajo fue evaluar el potencial bioacumulador de metales pesados en cinco especies forestales que viven en entornos mineros en la región amazónica ecuatoriana. Se analizó el factor de bioconcentración a partir de la relación entre la concentración de metales pesados en las hojas y el suelo para cinco especies forestales, tales como: Cedrela odorata, Parkia multijuga, Inga edulis, Cecropia ficifolia y Pourouma cecropiifolia, comúnmente distribuidas en la Amazonía ecuatoriana. Se utilizó espectrometría de absorción atómica para analizar los metales pesados en muestras de hojas y suelo de cada especie vegetal. Los resultados mostraron que P. cecropiifolia presentó el mayor factor de bioconcentración de plomo, C. odorata de cadmio y níquel, e I. edulis mayor potencial para absorción de hierro y aluminio. No se encontró correlación entre la concentración de los elementos en el suelo y las hojas, lo que demostró que la capacidad de bioacumulación de las especies estudiadas no depende de la concentración del elemento en el suelo. Esto facilita información relevante para la inclusión de estas especies con fines de fitorremediación.**

Palabras Clave: **especies arbóreas; contaminación; minería; hojas; suelos; factor de bioconcentración.**

I. INTRODUCTION

HEAVY metals are considered potentially toxic elements and one of the world's largest ecological problems, affecting human health both directly and indirectly [1]. They are natural constituents of the Earth's crust and are found in various components, such as the atmosphere, water bodies, sediments and the biosphere [2]. Among these pollutants, chromium (Cr), nickel (Ni), zinc (Zn), cadmium (Cd), lead (Pb), stand out as having attracted considerable attention due to their environmental persistence, toxicity and bioaccumulation [3]. These elements can bind to particles and be transported for several thousand kilometers by airflow, then deposited again through dry or wet deposition, ultimately resulting in high environmental concentrations [3]. Heavy metals are often associated with fine atmospheric particles and their transport distances depend mainly on meteorological factors, the physical and chemical characteristics of the particles, and atmospheric residence time.

Heavy metals have been investigated in various natural ecosystems [4] in both slightly and highly polluted areas, such as mining areas [5], agricultural regions [6] or urban environments, where heavy metal content originates mainly from various anthropogenic activities [7]. These anthropogenic activities can elevate metal

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concentrations above their normal levels and cause potentially toxic effects in the living world [8]. Although some heavy metals are also essential nutrients (e.g. copper and zinc) [9], they can be extremely toxic at higher concentrations or in a specific chemical form [10]. They tend to accumulate in biological organisms and soil over time, rendering them extremely hazardous [11].

Plants are extremely important because of their role in filtering air and releasing oxygen, regulating air temperature and accumulating potentially toxic substances [12]. Since some organs (roots and leaves) accumulate heavy metals [7, 13], they can serve as biomonitors of environmental pollution. The main sources of heavy metals in plants are their growth media and atmospheric deposition. Trees can absorb both essential and non-essential metals, and the uptake of heavy metals by both roots and leaves increases when the concentration of heavy metals increases in the external environment [7]. The accumulation of metal elements in plants confirms that these elements are present in the soil or air, but in many plants the concentrations of heavy metals can be several times higher than the concentrations of heavy metals in the soil [12]. The toxicity of these elements in plants varies depending on the plant species, type of metal, concentration, chemical form, soil composition, pH, type of sources (natural or anthropogenic) [9, 11]. Therefore, the leaves of specific tree species have been used as biomonitors of heavy metal pollution in several studies [14]. However, metal concentrations in tree organs are not a sufficient indicator of tree contamination, as uptake depends on the plant species and its bioconcentration factors, i.e. the ability of a plant to accumulate heavy metals from soil and air [15].

In the Ecuadorian Amazon, given the proximity of volcanoes, soils may have high levels of heavy metals [16]. In addition, mining operations are a major cause of environmental contamination, where mining waste management is inadequate. Consequently, heavy metals are easily released into the environment, posing a potential risk to human health. Artisanal and small-scale gold mining is among the most important causes of secretion of these elements into ecosystems, leading to severe pollution [17]. This has been widely reported in developing countries, where inefficient or non-existent environmental regulations exacerbate the problem [18]. This fact is particularly worrying in Ecuador as illegal and uncontrolled mining has produced serious environmental pollution, mainly in terms of discharges of potentially toxic elements [19]. These are not the only causes of heavy metal pollution; the population growth is also to blame in that it has led to the diversification of economic activity [20], the intensive use of toxic agrochemicals [21] and so on. Therefore, the objective of this work was to evaluate the bioaccumulator potential of heavy metals in five forest species that live in mining environments in the Ecuadorian Amazon region.

II. MATERIALS AND METHODS

A. *Study Area*

This study was carried out in a mining area near the banks of the Jatunyacu River in the Yutsupino community, Puerto Napo parish, Napo province, Ecuador (Figure 1), where illegal gold mining activities are carried out.

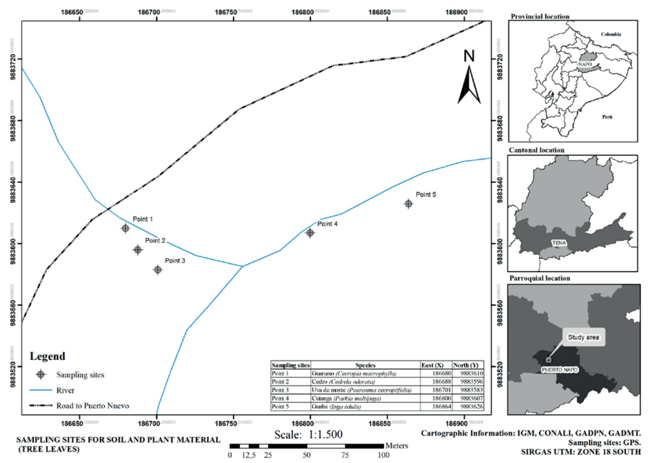

Fig. 1. Geographic location of the leaf and soil sampling sites of five forest species living in mining environments, Yutsupino community, Napo.

B. *Sampling of Plant Material and Soil*

For the analysis of heavy metals present in the plant material (leaves), five sampling points and ten trees per point were selected from five tree species that live in an area close to the mining site: *Cedrela odorata* L. (cedro), *Parkia multijuga* Benth. (cutanga), *Inga edulis* Mart. (guaba), *Cecropia ficifolia* Ward (guarumo) and *Pourouma cecropiifolia* Mart. (uba de monte) (http://www.theplantlist.org/). The selection of the five sampling points was carried out according to the location of the five species under study present at the mining extraction site. The species were selected based on their abundance, ecological and economic importance for the Amazon region.

The collection of leaf samples was carried out from individuals in an adult state, with exposure to the sun and in good physical condition. The plant material was collected from different sides of the trees, cutting the branches to prevent the leaves from facing the metal scissors. Leaves without mechanical damage or apparent disease were selected.

Soil samples were taken with an auger, at three different points at a depth of 0-30 cm within 30 cm around the selected trees. Soil sampling around the selected trees was in accordance with the methodology used by Greksa et al. [22]. A soil depth between 0 and 30 cm was used, as suggested by other authors [23]. Leaf litter and roots were removed. The samples obtained from different sides of the same tree and corresponding to the same soil unit were mixed in a bucket until the soil was homogenized and a composite sample obtained was representative of the collection, in an amount equivalent to 1000 grams [22]. The samples were placed in a plastic Ziploc bag, appropriately labeled and transferred to the Environmental Sciences Laboratory of the Universidad Estatal Amazónica, located in the main matrix Puyo, Ecuador, for subsequent processing and analysis of heavy metals: lead (Pb), cadmium (Cd), nickel (Ni), iron (Fe) and aluminum (Al).

C. Analysis of Soil and Leaf Samples

The plant material samples were washed with drinking water and then with distilled water. They were allowed to dry naturally on filter paper for four days and pulverized without the use of sharp metals, until obtaining a sample of 20 g. The soil samples were crushed and sieved through a 2 mm mesh sieve, then dried and a 100 g sample was obtained.

The collected soil and plant material samples were air-dried at room temperature for seven days before being taken to the forced circulation oven (Model ED-S 115, from Germany, with a temperature range from +7 °C to 250 °C) at a temperature of 40°C for 48 hours. The dried samples were placed in an agate mortar for grinding to a completely fine powder. The pulverized material was sieved to obtain particle sizes less than 2 mm [22]. A blank with 68 % nitric acid was used to verify possible contamination during the sample preparation process. A pre-labelled vial to process the digested soil and plant material samples was used. A mass of 0.5 g of each sample was weighed, and then, 7 mL of 68 % nitric acid (HNO_3), was added, followed by 1mL of 30 % hydrogen peroxide (H_2O_2). The vial was closed and placed in a microwave-assisted digestion apparatus (ETHOS ONE) for 50 minutes. This device used were 50 ml TFM (Modified Fluorine Teflon) containers to carry out the acid decomposition of the samples, ensuring exhaustive control of all reaction factors and compliance with strict safety and quality standards. The containers were placed in the microwave oven, which operated at 800 Watts and reached a temperature of up to 170 °C, for a predefined time until the temperature reached 40 °C. Once the wet digestion process was completed, the sample was allowed to stand at room temperature [24]. Once digested, the samples were transferred to a previously labelled volumetric flask, to which distilled water was added for a final volume of 25 mL. The samples were filtered prior to analysis and lastly, heavy metal determinations were performed on an Aurora Instruments LTD atomic absorption spectrometer with a data processer software Trace 1200 (Perkin Elmer, Model A Analyst 800, dimensions 1524.00 x 1016.00 x 812.80 mm, automatic sampler AS800, weight 136.08 kg), under the following conditions: flame type for the elements Pb, Cd, Ni and Fe, air-acetylene and nitrous oxide-acetylene for Al, with an airflow of 1.5 $Lmin^{-1}$ (air pressure 50 psi), acetylene flow of 3.5 $Lmin^{-1}$ (acetylene pressure 50 psi) and for hollow cathode lamp conditions, 20 mA current, slit width 0.2 nm and wavelengths of 217 nm, 228.8 nm, 232 nm, 248.3 nm and 309.2 nm for Pb, Cd, Ni, Fe and Al, respectively.

D. Data Analysis

An analysis of variance (ANOVA) and Tukey's test were performed, to determine the significance of the differences in heavy metals (Pb, Cd, Zn, Fe and Al) concentrations in the species analyzed (*C. odorata*, *P. multijuga*, *I. edulis*, *C. ficifolia* and *P. cecropiifolia*) as well as the concentrations of metals mentioned above in the soil around the place where they grow. A cluster analysis was performed to define the similarity between the heavy metal uptake capacity of the species, and Pearson's correlation coefficient was used to determine the correlations in the concentrations of the heavy metals analyzed in the plants and the soil. A Principal Component Analysis (PCA) to establish the separation of the analyzed plants according to the concentrations of heavy metals in soil and trees was done. Origin 2021 software was used for the statistical analyses.

The bioconcentration factor (BCF) was employed to measure each plant's ability to absorb heavy metals from the soil [15]. BCF was calculated using Equation (1):

$$BCF = {C_{leaves}}/{C_{soil}} \tag{1}$$

where C_{leaves} and C_{soil} represent the concentration of the element in the plant and in the soil, respectively.

III. RESULTS

A. Concentrations of Heavy Metals in Leaves and Soil

Figure 2a shows the results of the concentration of the heavy metals Pb, Cd, Ni, Fe and Al present in the leaves of *C. odorata*, *P. multijuga*, *I. edulis*, *C. ficifolia* and *P. cecropiifolia*, whilst Figure 2b shows the concentrations in the soils where those species grow. Foliar Pb concentrations ranged from 0.25 mg kg^{-1} in *C. odorata* to 7.05 mg kg^{-1} for *P. cecropiifolia*. Foliar Cd concentrations ranged from 0.08 mg kg^{-1} for *P. cecropiifolia* to 0.98 mg kg^{-1} in *C. odorata*. As for Ni, the lowest value was found in *P. multijuga* with a concentration of 1.80 mg kg^{-1} and the highest in *C. ficifolia* with 6.93 mg kg^{-1}. Fe values were 69.03 mg kg^{-1} in *C. ficifolia* and 99.02 mg kg^{-1} for *I. edulis*. Al was 109.4 mg kg^{-1} in *C. ficifolia* and 149.6 mg kg^{-1} for *C. odorata*.

Pb concentrations in soil ranged from 1.18 mg kg^{-1} for *C. ficifolia* to 1.89 mg kg^{-1} for *P. multijuga*. Cd values ranged from 1.49 mg kg^{-1} for *C. odorata* and *P. cecropiifolia* to 1.89 $mgkg^{-1}$ in *P. multijuga*. Ni concentrations ranged from 1.98 mg kg^{-1} around the place where *C. odorata* was located, to 3.60 mg kg^{-1} where *I. edulis* was grown. Fe in the soil had a minimum concentration of 198 mg kg^{-1} and a maximum concentration of 390.8 mg kg^{-1}, corresponding to *C. ficifolia* and *C. odorata* respectively. Al values ranged from 322.4 mg kg^{-1} in the soil around *I. edulis* to 542.2 mg kg^{-1} for *P. cecropiifolia*.

The Analysis of variance (ANOVA) and Tukey's test showed statistical differences in the concentration of the metallic elements Pb, Cd, Ni, Fe and Al in the leaves of the species studied, as well as in the soil where the species were grown (Figures 2A and 2B). For instance, *C. odorata* leaves had a significantly lower Pb concentration than *P. cecropiifolia* leaves. However, *C. odorata* had the highest Cd concentration, while *P. cecropiifolia* had the lowest Cd content. As for Ni, *P. multijuga* had the lowest concentration with significant differences to *C. ficifolia*, which was the species with the highest value. Yet *C. ficifolia* showed the lowest Fe and Al concentrations, whilst *I. edulis* and *C. odorata* had the highest Fe and Al values respectively (Figure 2A).

In general, the soil where the species grow showed significant differences in the concentration of heavy metals (Figure 2B). The lowest Pb concentration was in the areas of *I. edulis* and *C. ficifolia*, whereas the highest concentration was in the soil around *P. multijuga* and *C. odorata*. Cd concentration was similar in the locations of *C. odorata* and *P. cecropiifolia*. Indeed, the lowest and highest values of Cd were similar for the rest of the soil where the other species were found. Moreover, the presence of Ni in the soil had significant differences with lower values in soil surrounding *P. cecropiifolia* than in soil around *I. edulis*. As for the presence of Fe, where *C. odorata* is present, it had a higher content with significant differences to *C. ficifolia*. Al was higher in the soil around *P. cecropiifolia* and lower in *I. edulis* areas.

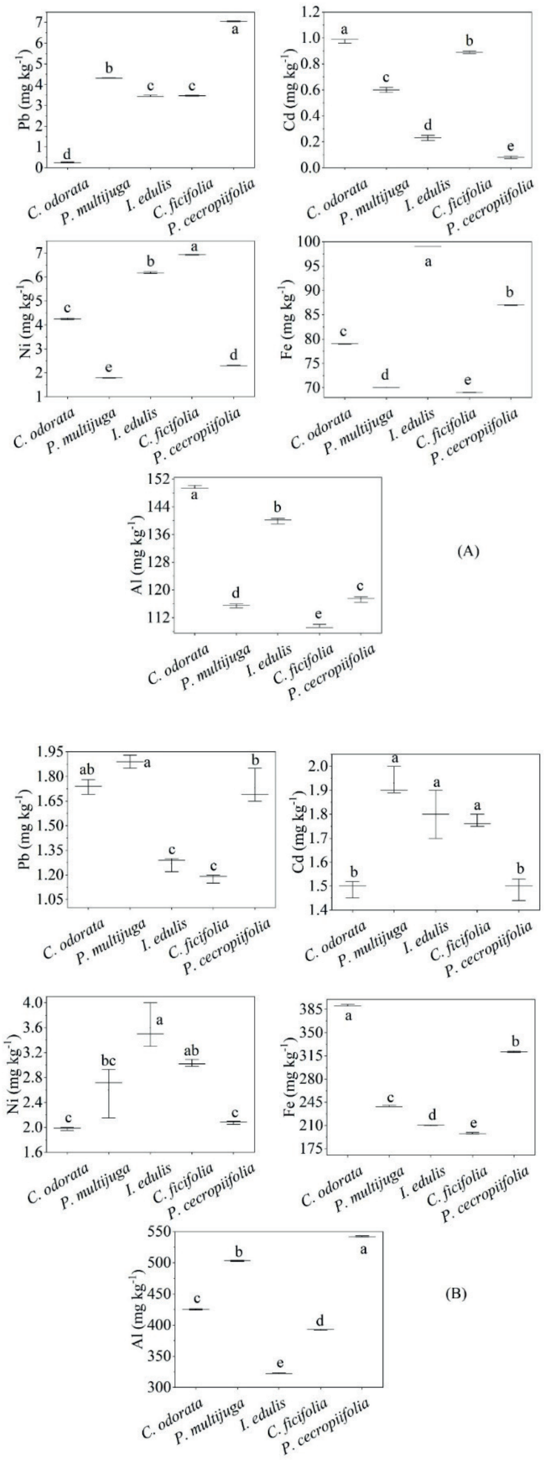

Fig. 2. Variation in the concentration of heavy metals (Pb, Cd, Ni, Fe and Al) of five forest species living in mining environments (A) Concentration in the leaves and (B) Concentration in the soil (Unequal letters indicate significant differences between species according to the Tukey test).

According to Pearson's correlation coefficient (Figure 3), when analyzing the concentration of metals in the leaves of the species studied, only a positive correlation (higher than 50%) was found between Al and Fe (r = 0.54). Meanwhile, other elements showed negative correlations: Cd and Pb (r = -0.79), Fe and Cd (r = -0.71) and Al and Pb (r = -0.69). Positive correlations higher than 50% between soil element concentrations were between Ni and Cd (r = 0.70), Fe and Pb (r = 0.62) and Al and Pb (r = 0.80), whereas Ni presented negative correlations with negative Pb, Al and Fe elements (r = -0.76, r = -0.77, r = -0.87), respectively.

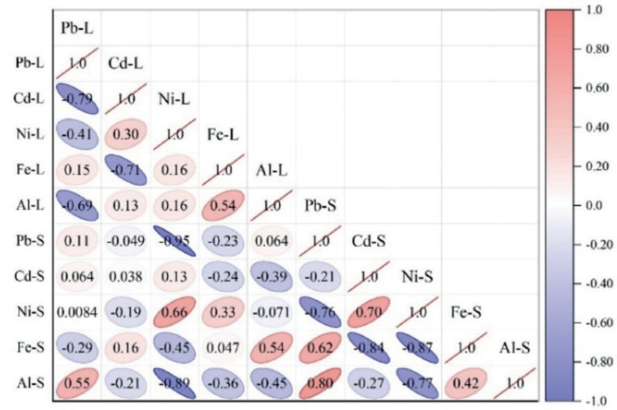

Fig. 3. Results of the correlation matrix between the concentration of heavy metals in the leaves and soil of five forest species living in mining environments. (The numerical value corresponds to the Pearson correlation coefficient).

The cluster analysis grouped all studied species into three groups based on the concentrations of heavy metals (Pb, Cd, Ni, Fe and Al) in leaves (Figure 4). Al concentrations in leaves of *C. odorata* and *I. edulis* formed one group; Fe concentrations in *P. cecropiifolia*, *I. edulis*, *C. ficifolia*, *P. multijuga* and *C. odorata*, and Al concentrations in *P. cecropiifolia*, *C. ficifolia* and *P. multijuga* formed the second group; while the third group included Cd, Ni and Pb concentrations.

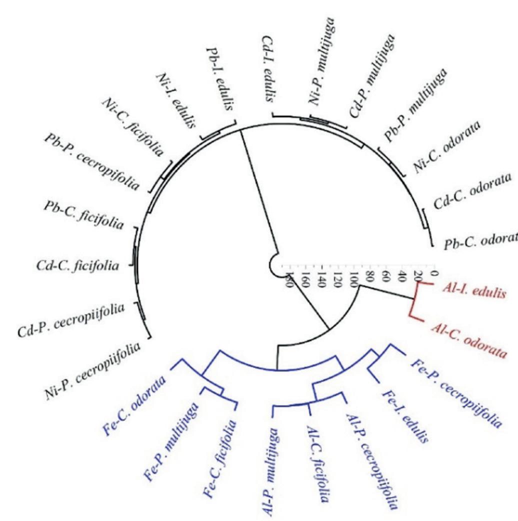

Fig. 4. Cluster analysis for the classification of similarity groups based on the concentration of heavy metals (Pb, Cd, Ni, Fe and Al) in leaves of five forest species living in mining environments.

The bioconcentration factor was used to estimate the plants' ability to absorb certain heavy metals from the soil. The BFC values can be seen in Figure 5. The species analyzed differ significantly in their capacity to absorb the heavy metals studied, with *P. cecropiifolia* having the greatest capacity to retain Pb, *C. odorata* accumulating the greatest amount of Cd, and *C. ficifolia* and *C. odorata* absorbing the most Ni. As for Fe and Al, I. edulis had the highest bioaccumulation potential for both elements.

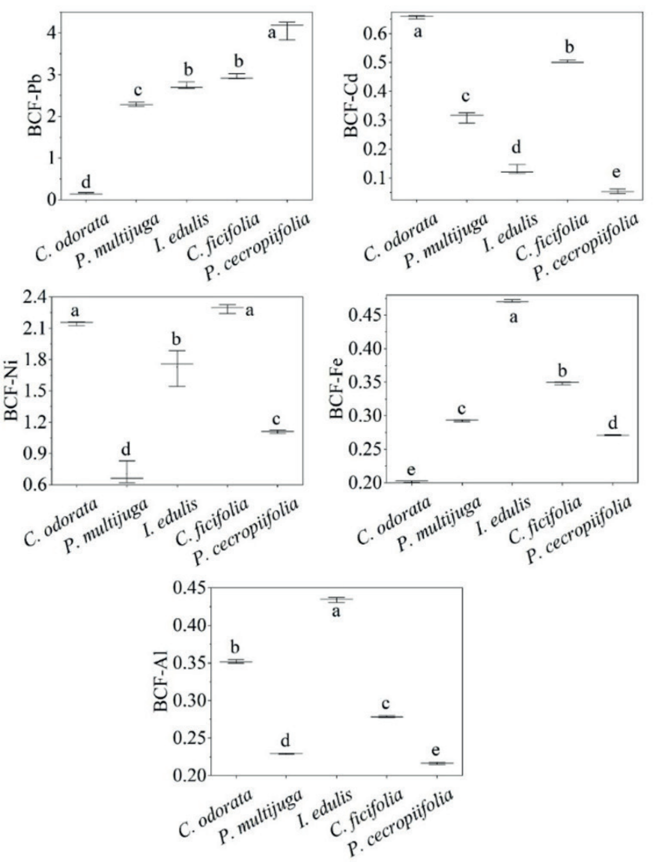

Fig. 5. Variation of heavy metal BCF among five forest species living in mining environments. (Unequal letters indicate significant differences between species according to the Tukey test).

From the eigenvalues of the correlation matrix of the heavy metals studied and using the PCA method, the initial data set was reduced to two principal components that explained 70.6 % of the variability. Based on the PCA analysis, Ni and Cd concentrations in the soil were lower than those of Fe, Pb and Al (PC 1). When looking at the plants in the coordinate system, determined by the principal components, it can be noted that the PC 1 axis separates the species *C. odorata*, *P. cecropiifolia* and *P. multijuga*, which are on the positive side of the axis and had lower values of Cd and Ni in the soil, from *I. edulis* and *C. ficifolia*, which are on the negative side of the axis and are characterized by higher concentrations of Cd and Ni in the soil. The second axis, PC 2, separates the species *C. odorata*, on the positive side of the axis and with a lower Pb concentration, from the rest of the species (Figure 6).

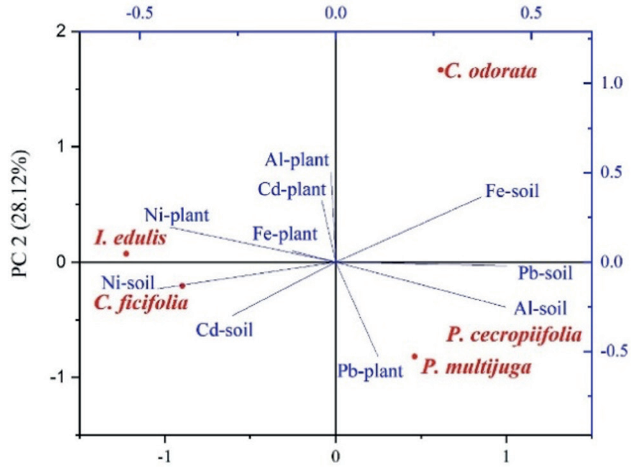

Fig. 6. Results of the PCA analysis of the concentrations of heavy metals (Pb, Cd, Ni, Fe and Al) in leaves and soil of five forest species (C. *odorata, P. multijuga, I. edulis, P. cecropiifolia* and *C. ficifolia*). X axis: PC1 (principal component 1); Y axis: PC2 (main component 2).

IV. DISCUSSION

The leaf material of five forest species, *C. odorata, P. multijuga, I. edulis, C. ficifolia* and *P. cecropiifolia*, which commonly inhabit mining areas in the Ecuadorian Amazon region, together with soil samples taken at a depth of 0-30 cm were tested. The objective was to identify which species had the potential to bioaccumulate Pb, Cd, Ni, Fe and Al to mitigate possible contamination by any of these elements in Amazonian ecosystems.

The variation found between the species *C. odorata, P. multijuga, I. edulis, C. ficifolia* and *P. cecropiifolia*, in relation to the concentration of heavy metals at the foliar level and in the soil, indicated a different response of the species as a reflection of the potential to accumulate Pb, Cd, Ni, Fe and Al.

The variability found in the concentration of heavy metals between species agrees with studies carried out for three woody species of ecological importance (*Piptocoma discolor*, *Bambusa vulgaris* and *Ochroma pyramidale*) that inhabit soils contaminated by mining in the province of Napo, Ecuadorian Amazon, which presented differences in the concentration of heavy metals [25]. Generally, the concentration of heavy metals in different parts of the plant depends on the amount of heavy metals in the air and soil, and it is different within and between plant species [26, 27]. The different responses of vascular plants to heavy metals can be attributed to genetic and physiological factors [28].

The concentration of heavy metals in the soil reflected that there is a high concentration of heavy metals in each of the sampling points at a depth of 0-30 cm. These results coincide with those reported by Šichorová et al. and Wu et al. [23, 29], where the maximum concentration was found in the soil layer within this depth range.

However, concentrations of heavy metals may be higher at depths greater than 30 cm, but their chemical forms differ with depth and therefore may not be readily available to plants [23].

The Cd concentration of the species in this study was higher than that reported by Alahabadi et al. [15] for different woody plants, where the values were between 0.34 and 0.62 mg kg^{-1}. According to Ecuadorian regulations [30], it was found that the concentration of Cd exceeded the permissible values (0.5 mg kg^{-1}), Pb and Ni were below the established limits, while Fe and Al are not regulated. The exceeded limits of Cd were similar to those reported by Chamba-Eras et al. [31] in a study of native hyperaccumulator plants with differential phytoremediation potential in an artisanal gold mine in the Ecuadorian Amazon. In contrast to what was reported by García et al. [25] in soils contaminated by mining in Napo, who obtained Cd concentration values within the tolerance range (0.04-0.35 mg kg^{-1}) for three study species (*P. discolor*, *B. vulgaris* and *O. pyramidale*), while the concentration of Pb resulted in toxicity for the species *P. discolor* in a range of 30-300 mg kg^{-1}. It is important to highlight the bioaccumulative potential of the species, regardless of whether the soil can be considered contaminated or not. If plants can absorb some of the elements considered contaminants, then this could be a viable option for bioremediation of contaminated soils.

When the content of heavy metals in the soil reaches levels that exceed the maximum permitted limits, they cause immediate effects such as inhibition of normal growth and development of plants, and a functional disturbance in other components of the environment, as well as the decrease in populations soil microbes [32]. The amount of heavy metals available in the soil can be a function of pH, texture, organic matter, cation exchange capacity and other soil properties [33]. Therefore, it is recommended for future studies to include analysis of the physical and chemical properties of the soil that will make it easier to understand the absorption capacity of heavy metals.

High levels of Cd contamination can cause detrimental effects on plants such as: decreased seed germination rate, lipid content and overall plant growth, induction of phytochelatin production and interference in establishment of the symbiosis between microorganisms and plants [34]. The results of this research reported a higher concentration of heavy metals (Pb, Cd, Ni, Fe and Al) in the soil than in the plant. This corresponds to studies carried out by Barthwal et al. [35] in several sites, which indicated that the level of absorption of heavy metals was higher in the soil than in the plants.

The low correlation found in this research between the concentration of heavy metals in the soil and the leaves could be related to the bioconcentration capacity of each species. The bioaccumulation capacity of plants does not depend entirely on the concentration of heavy metals in the soil but is related to the physiology of the plant and its protection capacity [36]. When plants are stressed by heavy metals, they can actively regulate the concentration of the elements [37].

The behavior that has been found in the species *I. edulis* and *C. ficifolia*, which are characterized by higher concentrations of Cd and Ni in the soil, could be given by the specific physiological mechanisms of bioaccumulation in these species. These results are interesting because they are fast-growing species, which grow naturally in anthropized sites, which suggests their use as phytoremediation species in sites where mining extraction practices are carried out and contamination by heavy metals of Cd has been proven or not.

The bioaccumulation factor (BCF) showed that *C. odorata* had a high capacity for the phytostabilization of Cd and Ni, while *I. edulis* presented a high capacity for Fe and Al and *P. cecropiifolia* a high capacity for Pb. This indicated the tolerance of these species to soils contaminated by these heavy metals, suggesting their use as potential species for phytoremediation. Previous studies have documented the heavy metal biosorption potential of *C. odorata*. For example, Akintola and Bodede [38] studied seedlings grown in landfill soils and deduced that heavy metal concentrations in contaminated soils indicated metal enrichment in plant tissues. Enrichment coefficients and distribution factors showed the potential of *C. odorata* as a bioaccumulator species. Thus, they concluded that seedlings of this species can be used to clean up or rehabilitate soils that are contaminated with the heavy metals studied (Cu, Pb, Zn and Co). This demonstrates the effectiveness and ability of *C. odorata* to accumulate and distribute heavy metals in its parts. In a study carried out at a mining site in Alacrán, Colombia, the Hg bioaccumulator potential of *I. edulis* has also been reported, where it has been used for phytoremediation in a mining site contaminated with this heavy metal [39].

In Ecuador, no reports have been found on the species under study regarding the capacity to accumulate heavy metals. However, in a study carried out in the tropical forests of southern Ecuador, the capacity of two native woody plants (*Erato polymnioides* and *Miconia sp*) to accumulate Cd, Pb, Zn and Hg was estimated, with the aim of developing effective strategies for the phytoremediation of mining sites. These species demonstrated high potential for bioaccumulation of heavy metals [31]. These results are interesting, since the species were characterized by their low productivity and high adaptability to the edaphoclimatic conditions of the region and have been used for the recovery of soils contaminated by mining. In the study, the species *I. edulis* presents similar characteristics to the species of this forest (low productivity and adaptability), so its high potential for accumulation of Fe and Al gives the possibility of including this species for phytoremediation in sites contaminated by mining.

For the species *P. multijuga*, *C. ficifolia* and *P. cecropiifolia*, no studies have been reported on the absorption capacity of heavy metals, so this research reports for the first time the bioaccumulative potential of these species.

These studies demonstrated the importance of research and the polluting effect that mining exploitation practices have without criteria or regulations that allow their use in a responsible manner. Illegal mining in Ecuador and the Ecuadorian Amazon is an environmental concern for the general population [40]. Therefore, phytoremediation emerges as a technique that uses specialized plants to absorb and accumulate heavy metals in their tissues.

Knowledge about the main weaknesses of large-scale mining worldwide constitutes fundamental information for the analysis of the current situation in Ecuador, which has prospects for large-scale production starting in December 2019, so knowing about These good practices and policies constitute application guidelines towards responsible mining [41].

V. CONCLUSION

The bioconcentration factor made it possible to identify the studied species' (*C. odorata*, *P. multijuga*, *I. edulis*, *P. cecropiifolia* and *C. ficifolia*) capacity to bioaccumulate the heavy metals Pb, Cd, Ni, Fe and Al, making it possible to propose reforestation in areas contaminated with these elements to mitigate the negative impacts they may cause on the ecosystem. For Pb-contaminated soils, *P. cecropiifolia* is recommended as it showed the highest CBF-Pb value. Furthermore, the species *C. odorata* can be used in Cd and Ni contaminated sites, while *I. edulis* showed the highest potential for Fe and Al uptake.

As no correlation was found between the concentration of the element in the soil and the leaves, it can be asserted that absorption depends on the bioconcentration capacity of the species. It is therefore suggested that more forest species inhabiting the Ecuadorian Amazon region could be studied as well as other heavy metals to broaden the identification of potential species, depending on the pollutant.

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