Phytoremediation Potential of Aquatic Plants in a Tropical River Basin: Metals Bioaccumulation and Translocation from Mine Water

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Abstract

This study aimed to evaluate aquatic plants that receive nickel mine runoff in Akelamo River, Obi Island, North Maluku, Indonesia, using Bioaccumulation Factor (BAF) and Translocation Factor (TF) to determine their phytoremediation potential. The predominant aquatic plant species identified in the Akelamo River belong to the grass family (Poaceae), specifically *Echinochloa* sp. This species accumulated primarily for Ni, Zn, Fe, Mn, Cu, with a high translocation potential for from roots to stems for Ni and Zn metals. These findings indicate that *Echinochloa* sp. plants, which grows naturally in rivers within nickel mining regions, can accumulate, and have the potential to phytoremediate, various metal.

Keywords: Aquatic plant, metal, bioaccumulation, phytoremediation

Introduction

Mining that employs open-pit methods has greater challenges when operating in countries within tropical rainforest regions, wherein rainfall is relatively high. Indonesia, as one of the tropical countries with the world's largest nickel reserves, has an average rainfall of up to 3000 mm per year, which is very high compared to sub-tropical countries with an average of 800 - 1000 mm per year (Eccles *et al*., 2019; ESDM, 2020; USGS, 2021). The complexity of tropical ecosystems and high rainfall can accelerate the process of moving various materials from mine water into water bodies, which has an impact on the balance of aquatic ecosystems that act as transport routes and transport various materials and pollutants (Abfertiawan *et al*., 2023; Karim *et al*., 2020).

Aquatic plants in river ecosystems act as bioindicators for the level of pollution due to their adaptation and tolerance mechanisms to metals. Being sedentary, relatively long-lived, and able to accumulate metals, aquatic plants are ideal for pollution monitoring. This also opens up opportunities to explore the potential of phytoremediation to absorb, accumulate and neutralise metal pollutants from the environment (Prasad, 2005; Singh *et al*., 2017; Qian, 2015).

This study evaluates the extent of metal accumulation in plant biomass to understand its phytoremediation capacity that grow naturally in a river that drains a nickel mining area. By understanding bioaccumulation mechanisms through Bioaccumulation Factor (BAF) and Translocation Factor (TF), we hope that effective mitigation approaches can be developed to reduce the impact of nickel mining activities on river ecosystems.

Methods

Study Area

The aquatic plants that were the subject of this metal bioaccumulation study were collected from a river that is the receiving water body of nickel mining activities on Obi Island, North Maluku, Indonesia (1°33'08.84''S and 127°25'52.50''E). While there are several mining catchment areas in the location (A-G) (Fig. 1), catchment area G is a mining area that specifically drains its outlet directly into

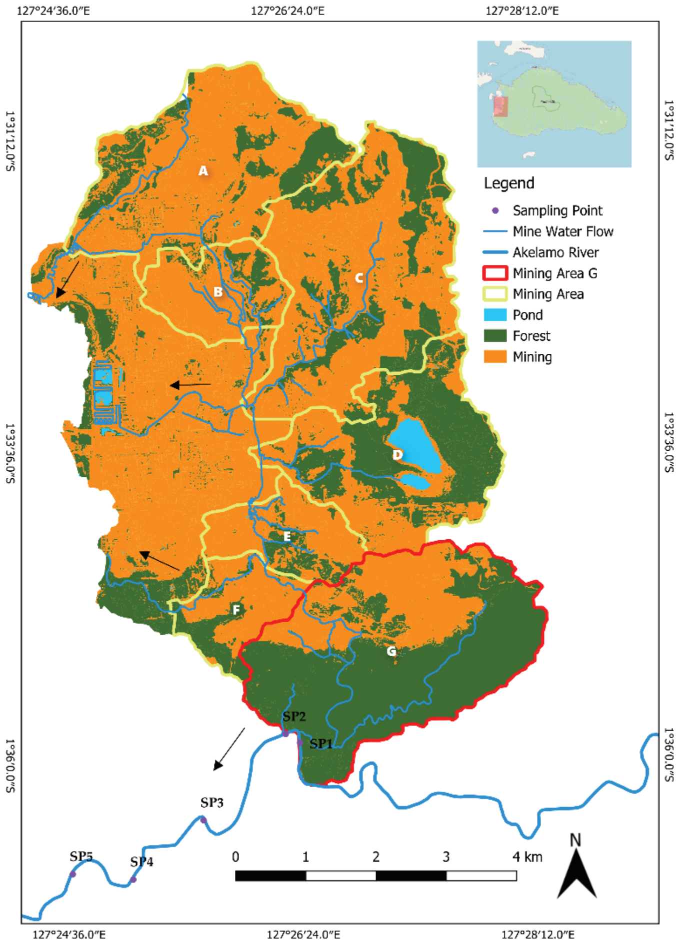

Figure 1 *Distribution of sampling site and location in study area.*

the main river, the Akelamo River. Samples of aquatic plants, sediments, and water were taken from five sampling points from the river upstream to downstream.

Sample Collection

The sampled aquatic plant parts include roots, stems, and leaves, using a shovel from the surface of river sediments. Samples of aquatic plants growing in the research area were collected, washed under running water, and placed in plastic bags for identification. The samples were dried at 95 °C to a constant weight, and crushed into fine powder for metal content analysis. Metals in aquatic plants were measured after acid digestion of the dried samples with an acid mixture (HNO3:H_2SO_4:$HClO_4$ dalam 5:1:1) at 85 °C until a clear solution was obtained. The solution was then filtered using 0.45 micron for analysis.

A total of 1 litre of river water were sampled and stored in polyethylene bottles. Sediment samples were taken using a shovel at a depth of 0-10 cm from the river surface. Wet samples were prepared by drying at 105 °C to constant weight, crushing to <63µm size, and digesting with aqua regia (HCl:HNO_3 dalam 3:1) (USEPA 3050B). Metal content for all samples was analysed using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS) (APHA 3125).

Data Analysis

Metal bioaccumulation was evaluated using the Bioacumulatiion Factor (BAF) approach which refers to the efficiency of aquatic plants to accumulate metals from the environment into their tissues. The BAF of different metals from sediment to aquatic plant and water to aquatic plant was calculated based on the dry weight of aquatic plant samples with the equation given by Wilson and Pyatt (2007) as follows:

$$BAF = \frac{C\ \text{plant tissue}}{C\ \text{sediment / water / soil}}$$

where $C_{\text{plant tissue}}$ is the concentration of metals in plant tissue (roots/stems/leaves) and $C_{\text{(sediment/water/soil)}}$ is the concentration of metals in sediment, water, or soil.

Translocation Factor (TF) was used to describe the accumulation of metal concentrations from roots to other plant parts, such as stems and leaves/shoot. Its value was calculated based on the following equation (Zacchini *et al.*, 2009):

$$TF = \frac{C\ \text{aerial parts}}{C\ \text{root}}$$

where $C_{\text{aerial parts}}$ is the metal concentration in the leaves/shoot or stems and C_{root} is the metal concentration in the roots.

Result and Discussion

Aquatic Plant Identification and Metal Content

The identification of aquatic plants at the sampling point of Akelamo River showed that the grass species (Poaceae) *Echinochloa* sp. was the most abundant among aquatic plants. The genus *Echinochloa* consists of more than 250 species of plants that are widely distributed throughout the world, especially in tropical areas with dry or waterlogged soil conditions. These aquatic plants have fibrous roots, flat stem, and hairy, glabrous, nodes, which are characteristics that enable the plants to survive and adapt to various environments (Damalas *et al.*, 2008; Marambe and Amarsinghe, 2002). A population of *Echinochloa colona* is known to grow naturally in the former chromite mine area (Rout *et al.*, 2000), in which this species has developed tolerance to metals. According to Rout *et al* (2000), this tolerance is maintained by a genetic system that is balanced by natural selection, making it suitable in restorations designed to produce effective vegetation cover to improve mined land and reduce erosion. Other studies have also shown that this plant can be useful in phytoextraction and revegetation programs on mining waste containing metals, due to its ability to accumulate metals (Peng *et al.*, 2017; Subhashini *et al.*, 2016; Sultana *et al.*, 2015). Metal concentrations in aquatic plants, sediment, and surface water collected from Akelamo River are shown in Table 1.

Among the various sampling points, the highest concentration of metal Fe (14018.5 mg/kg), Mn (475.40 mg/kg), Cr (79 mg/kg), Cu (29 mg/kg) was recorded in the root of *Echinochloa* sp., and Ni (17.63 mg/kg), Zn (62.22 mg/kg) was found in *Echinohloa* sp. stem. Minimum metal contents were found in *Echinochloa* sp. leaves. In this aquatic plant, metals were primarily accumulated in the roots, followed by stems and leaves. Metal concentration of sediment follows this order: Fe (6582.98 mg/kg) > Mn (238.37 mg/ kg) > Cr (72.89 mg/kg) > Zn (22.87 mg/kg) >

Table 1 *Metal concentration in aquatic plant, sediment, and surface water.*

Metal Element	*Echinochloa* sp. (mg/kg) (Mean ± SE)			Sediment (mg/kg) (Mean ± SE)	Water (mg/L) (Mean ± SE)
	Root	Stem	Leaf		
Ni	14 ± 11	17.6 ± 13.4	9.7 ± 8.1	6.1 ± 3.6	0.01 ± 0.00
Fe	14018.5 ± 16570	5229 ± 73.8	4035.5 ± 6243.2	6582 ± 826	0.43 ± 0.24
Mn	475.4 ± 471.8	245.8 ± 293.5	10.4 ± 97.2	238.3 ± 88.5	0.06 ± 0.03'
Cr	79 ± 60.4	37.6 ± 43.7	33.2 ± 44.7	72.9 ± 30.1	0.05 ±0.03
Cu	29 ± 30.8	16.3 ± 21.8	10.4 ± 12.9	19.3 ± 3.1	0.01 ±0.00
Zn	52.7 ± 56.9	62.2± 57.4	32.9 ± 28.4	22.8 ± 6.5	1.14 ± 0.39

Cu (19.29 mg/kg) > Ni (6.12 mg/kg), while decreasing trend of various metals in surface water was observed in this order: Zn > Fe > Mn > Cr > Ni > Cu.

Metals can be absorbed by aquatic plants or macrophytes through roots from sediments or leaves/shoots directly from the water column. Metal uptake by roots and leaves increases as the metal concentration in the medium (water or sediment) increases. However, uptake is not always linear with increasing concentration because metals are bound to tissues with saturation or tolerance limits (Greger, 2004).

Bioaccumulation and Translocation Factor

Bioaccumulation Factor (BAF) is commonly used to describe how much a plant is able to store pollutant materials such as metals, whereas its phytoremediation ability is generally characterised by Translocation Factor (TF). The BAF and TF for metals found in the aquatic plants of *Echinochloa* sp. in Akelamo River are shown in Table 2.

As shown in Table 2, the BAF values for *Echinochloa* sp. plants of metals found are ranging from 1.08 to 7.19 according to the following order, from the largest: Ni (2.35) > Zn (2.31) > Fe (2.13) > Mn (1.99) > Cu (1.50) > Cr (1.08). BAF < 1 or BAF = 1 indicates that plants are able to absorb metals, but do not always accumulate them, while BAF > 1 indicates the plant ability to accumulate metals in its tissues, categorising the plant as a hyperaccumulator (Satpathy *et al.*, 2014). With BAF > 1, *Echinochloa* sp. that grows naturally in Akelamo River is able to accumulate metals, the three with the highest values being Ni, Zn, and Fe. A previous study by Subhashini *et al* (2016) also confirmed that *Echinochloa colona* is effective in absorbing Zn and Ni.

TF with a value > 1 is categorised as an indicator of high efficiency in translocating metals from roots to other parts such as stems and leaves/shoots (Majid *et al.*, 2016). This study showed that the order of TF values from roots to stems was Ni > Zn > Cu > Mn > Cr > Fe, while from roots to shoots Ni > Zn > Cr > Cu > Fe > Mn. The findings showed that the TF value from root to stem was more than one for Ni (1.23) and Zn (1.18), indicating high translocation ability. Plants with Bioaccumulation Factor and Translocation Factor of more than 1 (BAF and TF > 1) have a phytoextraction potential, while plants with Bioaccumulation Factor value above one but a Translocation Factor less than one (BAF > 1 and TF < 1) have a phyto-stabilisation potential (Subhashini *et al.*, 2016; Yoon *et al.*, 2006). The success of the phytoextraction process depends on the plant's ability to move metals to tissues other than roots (Ma *et al.*, 2001; Majid *et al.*, 2014). *Echinochloa* sp. growing naturally around the Akelamo River can therefore be considered as a hyperaccumulator for phytoremediation and has the potential for phytoextraction, especially for Ni and Zn metals, since they tend to accumulate higher in the stem than in the roots.

In contrast, the metals Fe, Mn, Cr, and Cu have TF values less than 1, indicating that the amount of metals accumulated in root tissues

***Table 2** Bioaccumulation and Translocation Factor of metals in aquatic plants from Akelamo River.*

Metal Element	*Echinochloa* sp.		
	BAF (Root/Sediment)	TF (Leaf/Root)	TF (Stem/Root)
Ni	2.35	0.68	1.23
Fe	2.13	0.29	0.37
Mn	1.99	0.02	0.52
Cr	1.08	0.42	0.48
Cu	1.50	0.36	0.56
Zn	2.31	0.62	1.18

is greater than the amount found in stem or shoot tissues. Thus, although plants are able to accumulate metals in root tissues (BAF > 1), the ability of plants to translocate metals to other plant tissues is still limited (TF < 1), as such that they accumulate more of Fe, Mn, Cr, and Cu metals in root tissues and have more potential for phytostabilisation.

We think that the high concentration of Fe metal measured in the roots is due to the high concentration of Fe in the sediment (Table 1). The nickel mine that discharges water into the Akelamo River is a nickel laterite known to produce large amounts of Fe from the laterisation process (Elias, 2002). Despite high Fe concentrations in the roots, TF to the stem or leaves was low, characterised by TF < 1 (Table 2). Fe translocation from roots to stems or shoots depends on the level of Fe treatment and is specific to aquatic plants (Mnafgui *et al*., 2022; Siquera-Silva *et al*., 2012). We suspect that the roots in these aquatic plants may act as a barrier that prevents Fe translocation to other tissues. Oxygen released by the roots can increase oxidising conditions resulting in the deposition of metallic elements on the root surface (Chauduri *et al*., 2014; Machado *et al*., 2005).The high productivity of BAF and TF in the tropical region may be due to the thermocline that tends to be stable throughout the year. In addition, the combination of intensive sunlight exposure and high rainfall effectively recycles nutrients through plant biomass (Pau *et al*., 2018).

Conclusions

As a tropical nation with high rainfall and the largest nickel reserves in the world, nickel mining in Indonesia has the potential to manage mine water entering rivers with a natural biota-based approach. This study demonstrates that *Echinochloa* sp, which grows naturally in the Akelamo River-a receiving water body of nickel mining effluent-is able to accumulate the metals Ni, Zn, Fe, Mn, Cu, and Cr, as indicated by Bioaccumulation Factor (BAF) values > 1. In addition, this plant has a high potential to translocate metals from roots to stems, especially for Ni and Zn metals, as indicated by Translocation Factor (TF) values > 1. Therefore, *Echinochloa* sp. can be considered as a hyperaccumulator for phytoremediation and has the potential for phytoextraction especially of Ni and Zn metals, as those metals tend to accumulate higher in the stem than in the root.

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