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Assessing phytoremediation potentials of heavy metals on selected plants species in the restoration environments of Gold Mining Area

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Abstract. Mining activity have impacts on the environment which potentially expose heavy metals. Therefore, it is necessary to design the reclamation in order to improve the restoration. This research aims to assess the phytoremediation of potential acid forming (PAF) reclamation area of Henny Dump. The research was carried out by identifying the plant species, and then measuring the plant vegetation index, and measuring the concentration of heavy metals. The research showed that *Falcataria molucana* (IVI: 150%) and *Gmelina arborea* (IVI: 150%) are species with the highest Important Value Index (IVI). The soil analysis result for total concentrations of ferrous (Fe), copper (Cu), zinc (Zn), and mangan (Mn) showed that the most significant decrease in the four-year period i.e., Ferrous. *Falcataria moluccana* and *Gmelina arborea* as the fast-growing species for restoring the reclamation area which can survive in low acidity concentrations and high of heavy metals ferrous concentrations. These fast-growing species are tolerant in high concentration of ferrous and low acidity of soil quality, as well have the potential to absorb the essential heavy metals of ferrous, where in 2019 the iron concentration was 39,575 ppm and in 2022 was 7,100 ppm
Keywords: Heavy metals, phytoremediation, reclamation

1. Introduction

Restoration is an effort to restore natural resources that have been damaged to nearoriginal condition. Phytoremediation is the process of removing waste and pollution from the environment by using plants and their components [1]. Phytoremediation techniques are commonly used to restore environments polluted with heavy metals such as Pb, Zn, and Au, as well as radioactive pollutants such as CSL (*Crosshole Sonic Logging*). This is a technique for bioconcentrating hazardous compounds (pollutants) in soil and water which is positive, environmentally friendly, and cost-effective [2]. Phytoremediation includes *phytoextraction, rhizofiltration, phytodegradation*, *phytostabilization*, and *phytovolatilization*. *Phytoextraction* involves the absorption of contaminants by plant roots as well as the transfer or accumulation of substances to plant parts such as roots, leaves, and stems. *Rhizofiltration* use plant roots' ability to absorb, precipitate, and collect metals from the waste streams. *Phytodegradation* refers to the metabolism of contaminants in plant tissues by dehalogenase and oxygenase enzymes. *Phytovolatilization* occurs when plants absorb contaminants and release them into the air through their leaves, or when certain chemical compounds are produced to immobilize contaminants in the rhizosphere [3]. Due to the fact that the majority of plant roots are found in the soil, these roots can remove metals through filtration, adsorption, cation exchange, and plant-induced chemical changes in the rhizosphere [4]. All heavy metals are considered environmental contaminants because they are hazardous at high doses [5].

Heavy metal pollution has become a major issue all over the world. When heavy metals are extracted and processed from ore, they are released into the environment. The issue of heavy metal pollution has become worse as industry has expanded and natural biogeochemical cycles have been disrupted. A large number of metallic elements are not degradable chemically or biologically. Unlike organic pollutants, which can be oxidized into carbon dioxide by microbial activity. Heavy metals are classified as either essential or non-essential based on their role in biological systems. Essential heavy metals, such as iron, manganese, copper, zinc, and nickel, are heavy metals that organisms require in small amounts to support physiological and biochemical functions. Non-essential heavy metals, such as cadmium, lead, arsenic, and hydrogen, are heavy metals that are not required in large amounts by organisms to support physiological and biochemical functions.

To be able to repair a post-mining area that is high in heavy metal elements, it is necessary to consider the types of plants that can reduce heavy metals and are hyperaccumulators, namely sungkai (*Perunemainerme*), sengon putih (*Paraserientesfalcataria*), mahogany (*Swietenia mahagoni*), jabon (*Anthocephalus cadamba*), meranti (*Shorea sp*), galam (*Melaleuca leucadendra*), eucalyptus (*Melaleuca cajuputi*), pine (*Pinus mercusii*), gempol (*Nuclea orientalis*), and banyan (*Ficus benjamina*). For ground cover plants and organic matter producers, *citronella, Mucuna Chochinensis, Calliandra, Gliricidia* and *Peltophorum* are recommended [6].

Plants have several advantages. Some plant species are heavy metal tolerant and hyperaccumulators; many types of plants can reduce pollutants; the release of genetically modified plants into the environment is more controllable than microbes; plants provide aesthetic value; and plants can penetrate the soil with their roots, which can reach 100 x 106 km per ha [7].

Heavy metals are divided into two categories based on their importance to biological systems: essential and non-essential. For crucial physiological and metabolic processes, living organisms require only trace amounts of essential heavy metals. Fe, Mn, Cu, Zn, and Ni are a few examples of essential heavy metals [8]. Heavy metals that are non-essential are those that are not required by living things for any physiological or metabolic processes. Nonessential heavy metals include Cd, Pb, As, Hg, and Cr. Beyond-threshold levels of heavy metals are harmful to health because they interfere with normal function [9].

Iron is an essential co-factor for many essential enzymes and a key part of electron chains. Only a few bacteria have the ability to replace iron with other metals, making it an essential component of almost all life forms. Iron is required for the production of chlorophyll and photosynthesis in plants. The distribution of plant species within natural ecosystems is governed by the availability of iron in the soil, which also has an impact on crop productivity and nutritional value. Reduced fitness, interveinal chlorosis, and slower growth are all the effects of insufficient iron intake. In order to counteract iron deficiency-induced anemia, one of the most common nutritional disorders worldwide, sufficient iron levels in food crops are essential. However, cells become poisonous when exposed to excess iron. Therefore, plants must find a way to get around the often-limited availability of soil iron. Since of the iron concentrations in reclamation area of Henny Dump (HD) are relatively high and the acidity is relatively low, based on the good mining practices, it must be reclaimed, thus it is necessary to set up the plant species which are tolerant of the high concentrations of heavy metals and low acidity.

2. Materials and methods

2.1. *Study sites*

The research was conducted in Henny Dump (figure 1). The research was performed in some stages namely studying the plant species that are tolerant of soil media that has a high Fe content at HD, checking data of soil analysis result during 2019, 2020, 2021, 2022 using the reagent method HNO_3 + $HClO_4$ (nitric acid + perchloric acid) and measuring it with atomic absorption spectrophotometer (AAS).

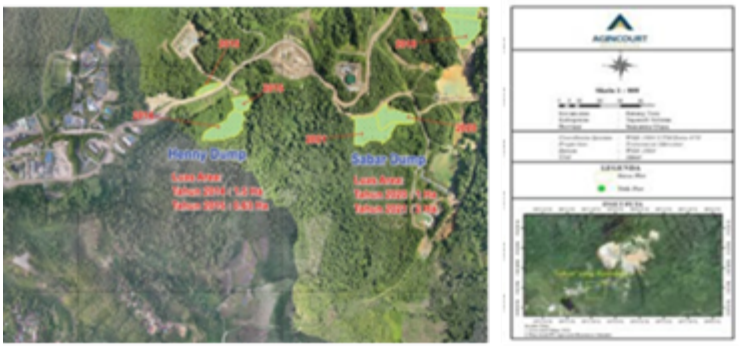

Figure 1. Map of the HD area

2.2. *Sampling*

Plots sampling was conducted in 2021 by purposive sampling in each plant age class, the quadratic approach was used to collect data in the revegetation area (figure 2). Approximately 3.93 hectares of the revegetation area became the object of observation at HD. In order to inventory the stages of seedling, poles, stake, and tree,smaller plot sizes were used inside the larger (20 × 20 m^2) plots for each variation of plant age [10].

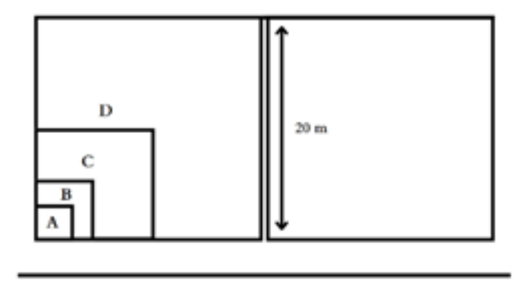

Figure 2. Design of the quadratic method for revegetated areas

To observe the diversity, Important Value Index (IVI) was used in this research. The IVI was calculated in HD locations, by the formula:

$$\text{Density}=\frac{\text{Number of individuals of a particular species}}{\text{Area of the entire sample plot}} \quad (1)$$

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$$\text{Relative density}=\frac{\text{Specific species density}}{\text{Density of all species}}\times 100\% \quad (2)$$

$$\text{Dominance}=\frac{\text{Total basal area of a particular species}}{\text{Area of the entire sample plot}} \quad (3)$$

$$\text{Relative dominance}=\frac{\text{Dominance of a particular species}}{\text{Dominance of all species}}\times 100\% \quad (4)$$

$$\text{Frequency}=\frac{\text{The number of sample plots found for a particular species}}{\text{Total number of sample plots}} \quad (5)$$

$$\text{Relative frequency}=\frac{\text{Frequency of a perticular species}}{\text{Frequency of all species}}\times 100\% \quad (6)$$

$$\text{IVI= relative density + relative frequency (seedling and saplings level)} \quad (7)$$

$$\text{IVI= relative density + relative frequency + relative dominance (stake and tree level)} \quad (8)$$

3. Results

3.1. Soil analysis results

The soil analysis in 2019 revealed that HD soil contained Fe, Cu, Zn, Mn, with the HD 02 area having the highest Fe content of around 50,300 ppm and the HD 04 area having a high Fe content of 43,800 ppm (table 1). The high Fe content in the soil will affect the plant root system, causing the surface of the leaves to become spotty and rusty, and the plant growth system to become stunted. Is slightly acidic, and the plant's leaves will suffer from a deficiency; an excess of the Fe nutrient will be toxic to plants (figure 3); the normal requirement for plants to absorb this nutrient is between 40 and 250 ppm. Over 500 ppm of iron content is hazardous to plants [11].

Table 1. Data from the soil analysis of the HD area

Location	2019					2020					2021					2022				
	P_2O_5	Fe	Cu	Zn	Mn	P_2O_5	Fe	Cu	Zn	Mn	P_2O_5	Fe	Cu	Zn	Mn	P_2O_5	Fe	Cu	Zn	Mn
HD 01	5.1	31,800	33	31	83	7.7	25,700	13	19	53	4.2	9,500	20.73	45.10	0.03	4,33	6800	25,4	34,9	327
HD 02	1.8	50,300	48	62	407	3.7	33,800	24	48	546	5.8	11,400	17.92	33.20	0.03	4,21	7400	17,4	35,6	243
HD 03	3.3	32,400	28	39	181	4.4	28,100	13	31	222	8.5	10,700	35.44	66.30	0.07	3,80	6900	12,4	34,4	540
HD 04	2.0	43,800	32	53	602	7	33,500	14	32	321	8.0	12,300	29.42	62.40	0.06	4,19	7300	24,5	41,5	555

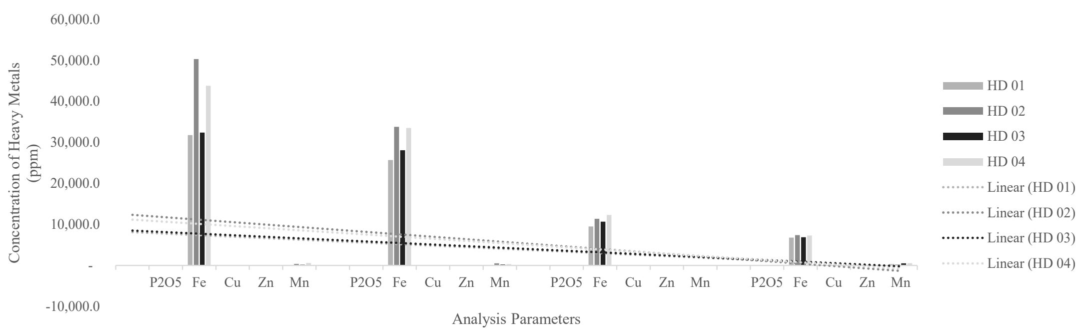

Figure 3. Heavy metals concentration from soil analysis results HD area

Plants' ability to absorb nutrients will be hampered by unsuitable pH levels. If the pH levels in the plant development media are acidic, plants won't be able to absorb nutrients as well, which will delay or hinder plant growth. The observation result showed the pH range HD area since 2019 to 2022 (figure 4) in the range of 3.3 and 4.8 (table 2).

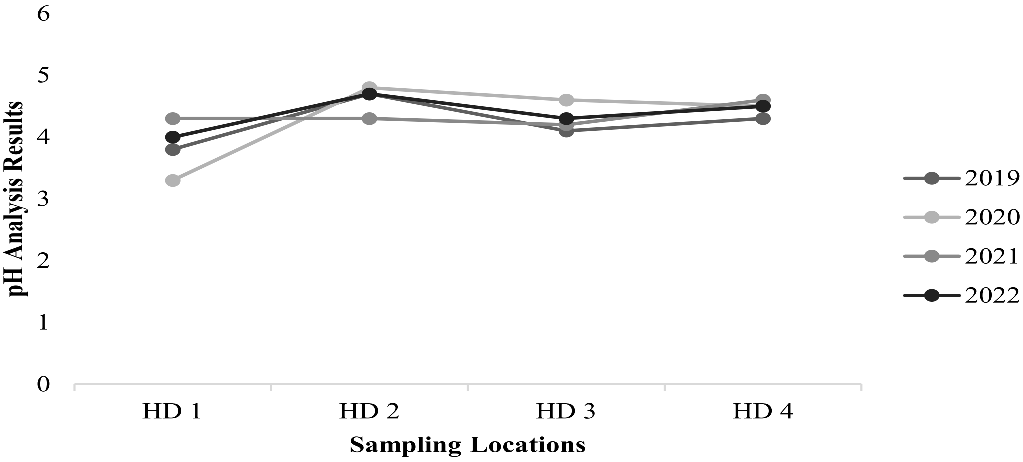

Figure 4. pH analysis results HD area

Table 2. Data from the pH analysis of the HD area

Locations	Years			
	2019	2020	2021	2022
HD 1	3.8	3.3	4.3	4.0
HD 2	4.7	4.8	4.3	4.7
HD 3	4.1	4.6	4.2	4.3
HD 4	4.3	4.5	4.6	4.5

3.2. Species diversity

Henny dump is a revegetation area that was planted in 2014. In the observation in 2021, this area had a temperature of 30.5°C, relative humidity of 7.5%, slope of 12 %, light intensity of 3301 luxs, CO_2 level of 389 ppm and soil pH of 4.55. At this location, 8 species of seedling and 4 species of sapling, stake and tree were found at different growth stages (table 3 and table 4). The species found at the site were planted in stake and tree level namely; *Eurya accuminata*, *Samanea saman*, *Falcataria moluccana*, and *Gmelina arborea*. Despite being planted at the same time, these species do not have the same growth rate because they have different growth rates. *Streblus elongatus* was still found as a seedling, *Eurya accuminata* and some *Samanea saman* as saplings, *Falcataria moluccana* and *Gmelina arborea* as poles, and some as trees. The different growth rates at the observation sites are thought to be related to the species adaptability to environmental conditions, particularly light factors, soil pH, mineral nutrients, species suitability, and competition in the observation area. In this area, *Falcataria moluccana* (sengon) and *Gmelina arborea* (jati putih) grows better with the important index value (IVI) 150% (figure 5). This species has the best growth because of its adaptability and ease of growth. When plants are resistant to high metal concentrations and do not exhibit phytotoxic or growth-detrimental effects, the removal of metals from soils can be more effectively accomplished [12].

4. Discussion

Mn, Cu, and Zn nutrient content is also included in the heavy metals needed by plants. According to Jones [13], normal concentrations of Mn, Cu, and Zn in plant tissue are between 50 ppm and 200 ppm. Table 1 shows that the Cu and Zn content is not more than 200 ppm, but the Mn content is more than

200 ppm, particularly in areas HD 02, HD03, and HD 04, due to this high Fe content, which makes the HD areas acidic in 2019 until 2022 and has the high potential to disrupt plant growth.

In 2020, the Fe content in the HD 01 to HD 04 area decreased, while the P_2O_5 content tended to increase in the HD 01 to HD 04 area. Even though the P_2O_5 content in the HD area is not high, the availability of P_2O_5 is in the between 3,7 and 7.7 ppm, indicating the quality of the soil and available organic matter so that soil can provide plant nutrients. However, under these actual conditions, the P_2O_5 content continued to improve soil organic matter, while the Cu, Zn, and Mn content decreased but increased in the HD 02 and HD 03 areas.

Table 3. The IVI in 2021 at the stake and treelevel in HD

No	Species	RD (%)	RF (%)	RBA	IVI (%)
		Stake			
1	*Eurya accuminata*	50	50		100
2	*Samanea saman*	50	50		100
		Tree			
1	*Falcataria moluccana*	50	50	50	150
2	*Gmelina arborea*	50	50	50	150

Table 4. The IVI in 2021 at the seedling and polestage in HD

No	Species	Local name	IVI(%)
1	*Asytasia gangetica*	Rumput Israel	83.33
2	*Eleutheranthera ruderalis*	Babadotan	27.78
3	*Hexastylis sp.*	Heartleaf (daun hati)	19.89
4	*Streblus elongatus*	Tempinis	127.59
5	*Eurya accuminata*	Jirak	100
6	*Samanea saman*	Trembesi	100
7	*Falcataria moluccana*	Sengon	150
8	*Gmelina arborea*	Jati Putih	150

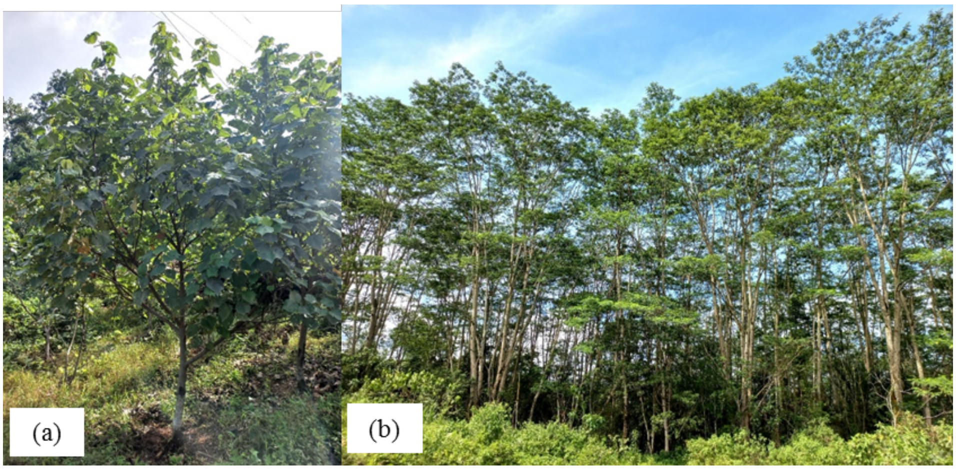

Figure 5. (a) *Gmelina arborea* and (b) *Falcataria moluccana*

The content of Fe and Zn decreased, as well as heavy metal Fe tended to decrease in 2022 due to the breakdown of organic matter and plants that absorb heavy metal elements. Therefore, the Fe content in the soil decreased in 2022 and it was continued with conducting soil analysis tests to see heavy metals in 2022, which also decreased. This indicates that several types of plants can absorb heavy metal content, causing soil conditions to gradually decrease in heavy metal nutrient Fe. Plants will be toxic to Fe nutrients and the normal requirement for plants to absorb this nutrient is 40-250 ppm. While Cu and Zn nutrients have increased, there has also been an increase in plant requirements for these nutrients, which range from 50 to 200 ppm. Table 2 shows that the heavy metal content of Cu, Zn, and Mn does not exceed the absorption of these micronutrients by plants.

The IVI for *E. accuminata* (jirak) and *S. saman* (trembesi) were both 100%, indicating that the higher the IVI, the easier the plants will adapt and grow. Trembesi is a plant with a broad canopy, which is why it is known as a shade plant. According to Putri [14], trembesi plants are capable of absorbing pollutants in their surroundings and are included in the phytoremediation plant family. The level of plant absorption of heavy metals around the area where the plants grow can be seen from the trend of soil analysis in HD, which shows that from 2019 to 2022 the content of the heavy metal Fe has decreased, while the IVI tended to high. Plants that have been reclaimed will be easy to grow and have the potential to absorb heavy metals, particularly heavy metal Fe. When plants are resistant to high metal concentrations and do not exhibit phytotoxic or growth-detrimental effects, the removal of metals from soils can be more effectively accomplished [15].

The higher IVI value and density found at the tree level than at the stake and sapling level, which is the IVI around 150%, with the plant species of *Falcataria moluccana* (sengon) and *Gmelina arborea* (jati putih). The high level of density will make it easier for plants to grow, able to improve the condition of the post-mining area at the HD location where the heavy metal concentration of Fe is high. Jati putih can repair damaged soil structures and also absorb heavy metal content in the soil, according to Zulkoni *et al*. [16], which states that soil conditions containing heavy metals will be absorbed by jati plants [17]. Aside from jati putih, the sengon plant potentially can absorb heavy metals in the HD area. Sengon plant, according to Sumiasri [17], can grow in both wet and dry wetlands, as well as in the low lands and high lands with a soil pH range of 4.75 – 7.85. The results of this observation show that *Falcataria moluccana* (sengon) and *Gmelina arborea* (jati putih) plants are able to grow well in low pH conditions, high Fe concentrations, as well as being able to reduce Fe concentrations in the soil.

5. Conclusion

Based on observations, the plant species that are tolerant of the heavy metal Fe are *Falcataria moluccana* and *Gmelina arborea*, which have high IVI values in HD revegetation locations. However, other types of plants in HD have good growth abilities with low pH quality and high heavy metal Fe concentrations, as demonstrated by the average Fe content level of 39,575 ppm in 2019 and 7,100 ppm in 2022. This type of plant in the HD area has the potential to absorb the heavy metal Fe, lowering the concentration of Fe based on the plant species age in the reclamation area. More research is needed to determine the amount of heavy metal Fe in plant roots, stems, and leaves, as well to identify and study arbuscular mycorrhizal colonization.

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