REDUCTION OF THE HEAVY METAL MERCURY (Hg) FROM PANINGKABAN GOLD MINING TAILINGS, BANYUMAS, WITH *AGERATUM CONYZOIDES*

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ABSTRACT

Gold is a fairly large contributor to Indonesia's foreign exchange. The area that has the potential to have minerals is Banyumas Regency. This area has been indicated to have gold mineral reserves of around 16,000 hectares. Until now, the gold processing process still uses mercury, which produces negative impacts such as post-mining waste containing heavy metal mercury (Hg), which can cause environmental damage. Environmental damage that arises, such as pollution of the soil and water environment, due to the gold bioleaching process that is disposed of without any treatment. One alternative that can be used to overcome this problem is by using hyperaccumulator plants. One plant that falls into the hyperaccumulator category is the bandotan plant (*Ageratum conyzoides*), because it is often found in gold mining areas contaminated with mercury. Mercury contamination will be absorbed from the environment into the body of *Ageratum conyzoides* through membranes and converted into less toxic substances. The aim of this research is to determine the ability of the *Ageratum conyzoides* plant as a phytoremediation agent in reducing mercury metal (Hg) in tailings from Paningkaban Village, Banyumas. There are two treatments, namely the planting media used with 2 kg of tailings soil and 2 kg of planting media mixed with tailings and compost. The mixture ratio between tailings and compost is 1:1. Each treatment, consisting of three replications, was observed using plant growth parameters (plant height and number of leaves), as well as control parameters (edaphic and microclimatic). The results of the research show that the *Ageratum conyzoides* plant is a phytoremediator agent that can reduce levels of the heavy metal mercury (Hg) in the planting medium of mining tailings soil from Paningkaban Village, because it gives test results of BCF values > 1 and TF < 1, which indicates that the *Ageratum conyzoides* plant has potential as a phytostabilizing agent.

Keyword: A Reduction; Hg; *Ageratum conyzoides*; tailing

Introduction

Indonesia is a country with an abundance of natural resources, both biological and non-biological, stretching from Sabang to Merauke. One of Indonesia's natural resources is mining. This vast mineral wealth makes Indonesia a net exporter of minerals, such as gold (Nugroho, 2020). Gold is a significant contributor to Indonesia's foreign exchange earnings. According to mining statistics from the Central Statistics Agency (BPS), gold mineral production in 2022 increased compared to the previous year, reaching 85,203 kg.

Banyumas Regency is a region with potential mineral resources. This area has been identified as having gold reserves covering approximately 16,000 hectares. One area in Banyumas Regency with gold ore reserves is Paningkaban Village, Gumelar District. The gold ore reserves offer potential for development as a community gold mining business, improving community welfare and thus impacting economic status (Aziz, 2014).

The presence of gold can have a positive impact, as many gold mining entrepreneurs, both legal and illegal, have emerged from the Paningkaban Village community. On the other hand, numerous negative impacts arise from the opening of gold mining sites. This causes environmental damage in the areas surrounding the mines. The gold processing process produces mine waste containing the heavy metal mercury (Hg). The traditional method of gold amalgamation extraction is carried out without proper management, resulting in mercury mixed with gold ore being released into the environment during the leaching process. Soil and water pollution is caused by mercury waste from the gold ore leaching process, which is dumped directly into the ground or rivers without treatment (Hasanah, 2022).

Mercury, also known as quicksilver, is a type of heavy metal with the chemical symbol Hg on the periodic table. Mercury increases the chemical composition of exposed organisms due to its bioaccumulation process. The accumulation of mercury in the environment can poison animals, plants, microorganisms, and humans, potentially causing toxicity to the central nervous system (Ghassani *et al.*, 2022). However, some organisms, such as plants, have good resistance to mercury (Hg) contamination.

Plants can accumulate heavy metal contamination and are therefore referred to as hyperaccumulators. Hyperaccumulators are plants capable of accumulating or absorbing heavy metals and converting them into various forms. These plants are useful in the phytoremediation process. Phytoremediation is a necessary method for reducing environmental pollution by using pollutant-resistant plants to absorb and transport specific contaminants. Mercury contamination is absorbed from the environment into the plant's body through its membrane and converted into less toxic substances (Ghassani *et al.*, 2022).

One plant that falls into the hyperaccumulator category is the bandotan plant (*Ageratum conyzoides*), as it is often found in mercury-contaminated gold mining areas. *Ageratum conyzoides* is one of the vegetation found in the Leon/B4 and Bulex/A2 prospects at the Rakatotok gold mine, and its BCF value is 0.01-0.1, indicating a low hyperaccumulator plant (Aminatun et al., 2024). This supports the potential of *Ageratum conyzoides* as a hyperaccumulator plant in this study. This study aimed to determine the ability of the *Ageratum conyzoides* plant as a phytoremediator agent in reducing mercury (Hg) metal in tailings from Paningkaban Village, Banyumas.

Methods

Tools and Materials

The tools used in this study included trowels, soil testers, hygrometers, lux meters, buckets, writing instruments, rulers, and soil thermometers. The materials used were 2-kg polybags, compost, mining tailings soil, bandotan plants (*Ageratum conyzoides*), and water. The tools used in this study included trowels, soil testers, hygrometers, lux meters, buckets, writing instruments, rulers, and soil thermometers. The materials used were 2-kg polybags, compost, mining tailings soil, bandotan plants (*Ageratum conyzoides*), and water.

Working Procedures

Preparing Tailings Samples as Planting Media

Tailings were collected from the mining area of Paningkaban Village, Gumelar District, Banyumas Regency, in the form of hard, dry soil balls that needed to be crushed using a wooden pestle. The tailings samples were then taken to the FMIPA UNY Greenhouse for mercury (Hg) analysis at the Environmental Laboratory of the Faculty of Civil Engineering and Planning (FTSP) at UII.

Tailings and Compost Content Testing

Tailings soil samples were tested for mercury (Hg) levels in the FTSP UII Environmental Laboratory before and after treatment to determine the level of mercury absorbed by the plants. The plants that had absorbed mercury were then tested for mercury (Hg) levels in the roots and stems of the Bandotan (*Ageratum conyzoides*) plants. The compost used in the phytoremediation process was tested at the Yogyakarta Centre for Environmental Health Engineering and Disease Control (BBTKLPP) to determine the N, P, K, and C/N content. These parameters were tested to determine the compost's maturity level.

Planting Media Preparation

Two planting media were used: 2 kg of tailings soil and 2 kg of a mixture of tailings and compost. The ratio of tailings to compost was 1:1 (Ulimma, 2016). 1 kg of tailings soil and compost were weighed, then mixed in a container and placed into 2 kg polybags, 2 kg for each treatment.

Acclimatisation and Planting of Bandotan (Ageratum conyzoides) Plants

The plants used were Bandotan weeds (*Ageratum conyzoides*). The selected plants were characterised by being green, fresh, and uniformly aged at 1 month. The plants were then acclimatised to the growing medium and placed in a greenhouse for one week. Nine Bandotan (*Ageratum conyzoides*) plants, previously acclimatised for one week and growing according to criteria, were planted in the growing medium for four weeks, using treatments consisting of tailings soil and a mixture of tailings soil and compost.

Maintenance and Measurement of Test Parameters

Observations in this study were conducted over four weeks. Measurements of plant growth, edaphic, and climatic parameters were carried out weekly, while mercury levels in the growing medium, roots, and stems were tested in the fourth week. Plant maintenance included regular watering.

Data Analysis Techniques

Data obtained from plant growth parameters, edaphic and climatic parameters, and Hg levels after treatment were analysed using quantitative descriptive methods. Quantitative descriptive research is research that describes, illustrates, and elaborates data in numerical form from a phenomenon with the aim of determining the relationship between variables within a population.

The Hg levels after treatment were then calculated using the Bioconcentration Factor (BCF) and Translocation Factor (TF) approaches. BCF is the ratio of the concentration of mercury metal in plants (roots and stems) to the concentration of mercury in the growing medium (Dulanlebit et al., 2021). The BCF value is obtained from the equation calculation:

$$\mathrm{BCF} = \frac{kandungan\ Hg\ dalam\ tanaman\ (mg/Kg)}{kandungan\ Hg\ dalam\ tanah\ (mg/Kg)}$$

The translocation factor value is needed to see the plant's ability to translocate the heavy metal mercury (Hg) from the roots to the leaves (Ismail et al., 2020). TF can be calculated using the formula:

$$\mathrm{TF} = \frac{kandungan\ logam\ berat\ pada\ daun\ (mg/kg)}{kandungan\ logam\ berat\ pada\ akar\ (mg/kg)}$$

Results and Discussion

Gold mining activities in Paningkaban Village harm the land because they cause significant damage. Unrehabilitated former mercury-contaminated mining land will become giant, open, infertile, arid, acidic, and physically grey puddles due to being mixed with mercury. As a result, only a few plants can grow because some plants are unable to survive on contaminated land (Hasanah, 2022). Data on the reduction in mercury (Hg) levels obtained from the measurement results will be analysed, and the BCF, TF, and plant performance values can be seen in the study. The following are the results of measurements of BCF, TF, and reduction in mercury levels in tailings before and after treatment on *Ageratum conyzoides* plants for 4 weeks. The measurement results can be seen in Table 1.

Tabel 1. Results of Mercury (Hg) Content Measurement Before and After Treatment

	Hg Before treatment (mg/kg)	Hg after treatment (mg/kg)			BCF		TF
	Tailing	Tailing	Root	Shoot	Root	Shoot	
BT	138	5.27	14.4	6.20	2.73	1.17	0.43
BTK	138	5.80	17.9	13.8	3.08	2.37	0.77

Description:
BT: Tailings planting media treatment without compost
BTK: Tailings planting media treatment with compost

The results of the mercury reduction test can be seen in Table 3, showing differences between the two treatments. *Ageratum conyzoides* plants were able to absorb more contaminants in the tailings planting medium treatment with added compost. This was evident in the mercury (Hg) levels in the roots and crowns of the plants. The addition of compost increased the supply of organic matter, which acts as a binder for mercury in the soil.

The humus content in compost can adsorb heavy metals through cation exchange, complex bond formation, and chelation. Mercury is immobilised in plant roots through accumulation, adsorption on the root surface, and deposition in the root zone (Borolla *et al.*, 2019). Meanwhile, in the treatment without compost, *Ageratum conyzoides* absorbed less mercury (Hg). This low mercury uptake may be due to the lack of added organic matter, which can provide high nutrient content and support bacterial growth in the soil.

Both treatments had higher mercury levels in the roots compared to the stems. Plants have entered the phytostabilisation process, where heavy metal contaminants attach to the roots and are not reabsorbed into the growing stem. The contaminants adhere stably and are therefore not carried away by water flow in the medium (Irhamni *et al.*, 2017).

The plant's ability to accumulate mercury can be seen from its BCF value. Based on the results of Table 3, it can be seen that the BCF value in the roots is greater than that in the plant canopy. In both treatments, the BCF value is categorised as >1, indicating that *Ageratum conyzoides* is a high accumulator plant capable of maximally remediating mercury (Hg). A BCF value >1 indicates a high accumulator plant capable of maximally remediating mercury (Hg) (Tuheteru *et al.*, 2017).

The amount of heavy metal translocation from roots to leaves can be determined by measuring the translocation factor (TF). The TF value is the ratio of heavy metal levels in the plant canopy to the levels in the roots. Both treatments had BCF values >1 and TF values <1, indicating that *Ageratum conyzoides* has the potential to act as a phytostabilizing agent (Rahman et al., 2021). Phytostabilisation mechanisms occur through the immobilisation, adsorption, and precipitation of heavy metals into soluble substances in plant roots. The process of stabilising contaminants in the roots limits contaminant mobility and bioavailability, resulting in low toxic effects (Kafle *et al.*, 2022).

The parameter measured to determine whether *Ageratum conyzoides* is a hyperaccumulator plant was plant performance when tested with both treatments. Plant height was measured weekly for four weeks of treatment. It was found that compost had no effect on plant growth, indicating that plants without compost grew taller. This data can be seen in Figure 1.

Figure 1 shows that the average plant height in the tailings treatment with compost added was stunted, and by week 3, the plants had died. Rhizobacteria in the roots of *Ageratum conyzoides* plants and the growing medium are known to produce the hormone IAA (Indole Acetic Acid). Rhizobacteria are rhizosphere bacteria that play a role in promoting plant growth by producing the growth hormone IAA, dissolving phosphate, and fixing nitrogen. This hormone efficiently enhances plant growth by increasing mineral nutrition and reducing heavy metal toxicity in plants, allowing plants to absorb heavy metals more quickly (Suharno *et al.*, 2023).

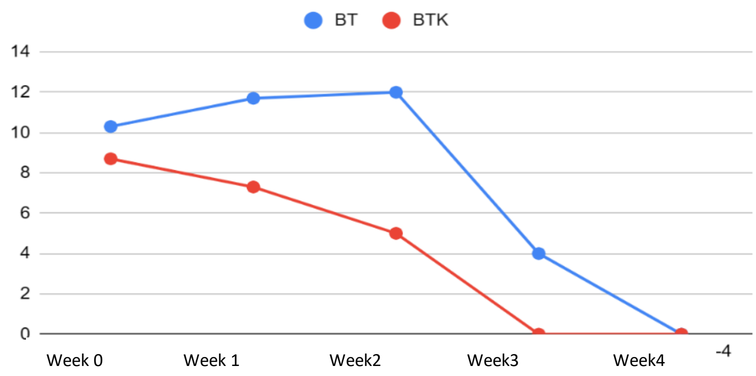

Figure 1. Plant Height

The IAA hormone produced by bacteria can accelerate plant growth, which in turn stimulates root differentiation, leading to root hair formation. Based on this, it can be concluded that the stunted growth of *Ageratum conyzoides* plants is caused by rhizobacteria, which only help plants reduce stress and reduce the toxicity of the heavy metal mercury. Furthermore, adding immature compost to the growing medium will cause competition between plants and soil microorganisms for nutrient absorption, resulting in unstable plant growth (Witasari *et al.*, 2021). Optimal plant growth can occur if environmental conditions support *Ageratum conyzoides* growth.

The tailings planting medium without compost treatment demonstrated better growth due to the absence of competition in the soil, enabling better plant growth. Plant death occurred in the 3rd and 4th weeks in both treatments. *Ageratum conyzoides* plant growth can be stunted and even die due to the unsuitability of the medium for plant growth. Furthermore, other factors that influence plant growth are edaphic and microclimatic factors. *Ageratum conyzoides* plants are highly adaptable to differences in temperature, humidity, and soil texture. This plant can grow well at temperatures of 20-25°C, but can adapt well to temperatures of 15-30°C. Based on measured microclimatic factors, it can be seen that the air temperature ranges from 29-34°C. This indicates that the air temperature exceeds the optimal range for *Ageratum conyzoides* growth, thus inhibiting plant growth and development. High accumulation of heavy metals in the roots also triggers saturation, which inhibits root growth, oxygen diffusion into the roots, and ultimately leads to plant death (Nurlina & Ruslan, 2016).

Another growth parameter tested in this study was leaf number. Leaf counts were conducted once a week for four weeks of treatment. The compost addition treatment showed no significant effect on the growth of new leaves. Data on leaf number increase can be seen in Figure 2.

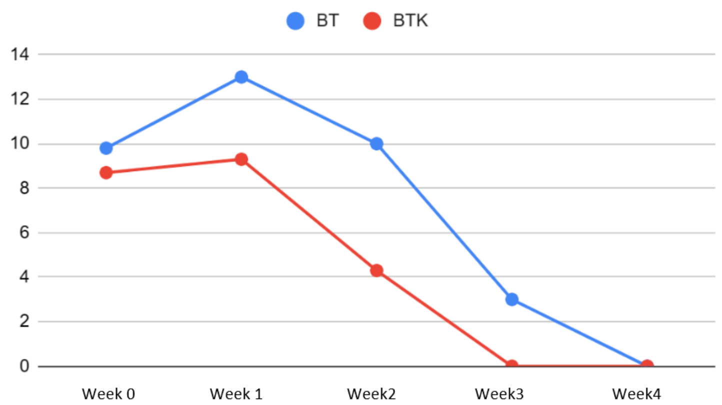

Figure 2. Number of Leaves

Figure 2 shows that the number of leaves on *Ageratum conyzoides* plants decreased with each week of observation. Metal uptake coincides with nutrient absorption, so the metal is distributed throughout all plant cells. However, plants have a limit to metal accumulation. High accumulation of Hg in plant parts triggers saturation, inhibiting oxygen diffusion into the roots and causing plant death (Nurlina & Ruslan, 2016). This affects the increase in leaf number.

Leaf loss occurred in each treatment, leading to plant death. Leaf loss can indicate evaporation of water because the roots are unable to optimally supply nutrients and water (Kurniawan *et al*., 2019). One form of poisoning resulting from high mercury levels is characterized by yellowing of the leaves, the appearance of brown spots on the leaves, which then wilt and eventually fall off. The higher the mercury concentration in the growing medium, the more it inhibits plant growth (Hidayati *et al*., 2016).

The edaphic parameter tested in this study was soil pH. Based on the results, the pH value in the growing medium ranged from 4 to 6. This indicates that the soil conditions in the treatments were acidic. Each polybag has a different pH value, allowing for the determination of the soil's properties. The pH data can be found in Figure 3.

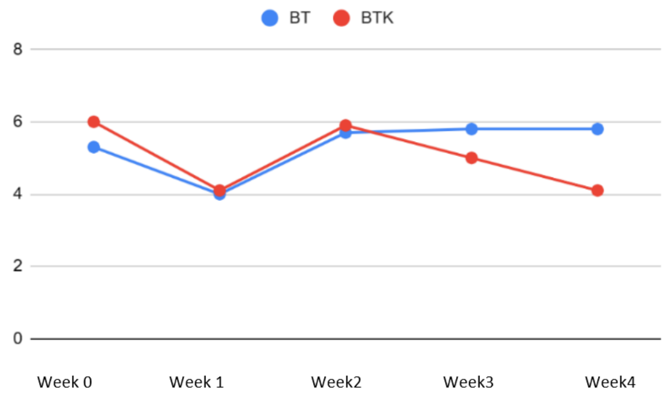

Figure 3. pH in Soil

During the phytoremediation process, soil pH is an important parameter because it supports plant growth and the rate of contaminant degradation. Soil pH gradually decreased significantly in the tailings + compost treatment. The addition of organic matter in the form of compost can buffer soil acidity, making it more neutral. However, the compost-added media treatment had a more acidic pH. This may occur because the compost used in this study was not fully mature, the organic matter had not yet decomposed properly, and the compost still released organic acids, which can acidify the environment (Rahmadanti *et al*., 2019). Meanwhile, the tailings-added media treatment was categorised as quite acidic. The acidic soil is also caused by the initial pH conditions at the Paningkaban Village gold mining site. *Ageratum conyzoides* plants can grow in areas with a pH ranging from 5 to 9. Therefore, a pH value <5 can inhibit the growth of *Ageratum conyzoides*.

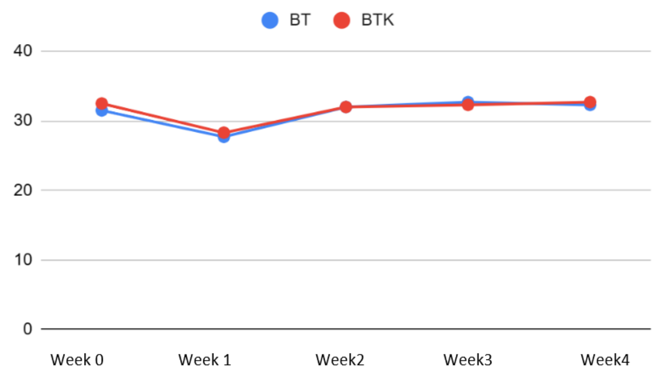

Figure 4. Soil Temperature

Observations of soil temperature parameters, measured weekly, revealed that the soil temperature ranged between 27 and 32°C in each treatment. The results show slight temperature differences, as shown in Figure 4.

In all treatments, soil temperatures remained relatively constant and remained relatively constant. High and low soil temperatures can be caused by the decomposition of organic matter by microorganisms, which generates and accumulates heat, transferring it from the surface. Hard soil surfaces also contribute to low soil temperatures, as surface heat cannot penetrate deeper into the soil layers (Hadi & Purnomo, 2022). Furthermore, soil temperature is significantly influenced by air temperature, daily weather, and light intensity. Light intensity can influence soil temperature because the amount of light reaching the plants directly affects the amount of solar heat absorbed by the soil (Karyati *et al*., 2018). Weekly measured soil moisture values for both treatments tended to be similar, ranging from 4 to 8. The results for both treatments showed no significant differences, as can be seen in Figure 5.

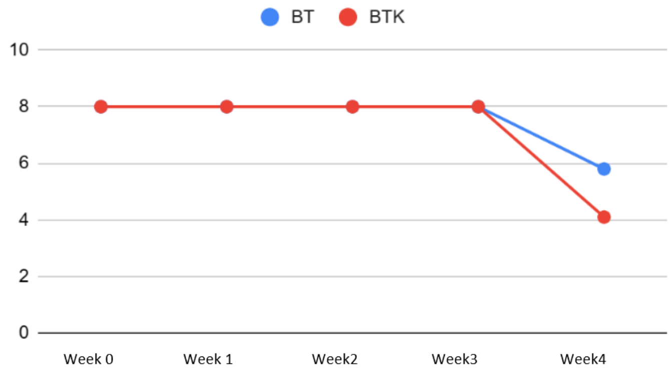

Figure 5. Soil Moisture

Soil moisture plays a role in soil fertility because it supports the availability of water in the planting medium. Based on the measurement results, it can be seen that the humidity of each treatment is in the wet category until the 3rd week. This indicates that the soil is wet and has sufficient water. With sufficient moisture, plants can absorb nutrients more optimally (Obenu & Kebumian, 2019). In the fourth week, humidity tends to decrease due to soil temperature and the addition of compost. In the compost addition treatment, soil moisture in the planting medium becomes higher due to the addition of organic material from the compost which causes the water content to be bound in the soil layer and does not immediately evaporate into the air (Karyati *et al*., 2018). The higher the soil moisture value, the more it will affect plant growth so that plant performance can be better in remediating contaminants.

Conclusion

Ageratum conyzoides plants are phytoremediator agents that can reduce the levels of heavy metal mercury (Hg) in the mining tailings soil planting medium from Paningkaban Village because they provide BCF test results> 1, which indicates that *Ageratum conyzoides* plants are high accumulator plants. As well as TF values with results <1 which indicate that the mechanism of *Ageratum conyzoides* plants is one of the good plants in reducing and remediating pollutants compared to other plants, because they are included in high accumulator plants with a phytostabilization mechanism. In the phytostabilization mechanism, mercury pollutants will stick and be immobilized in the rhizosphere of the plant so that they will not be carried away by water flow or contaminate the soil.

References

Aminatun, T., Idrus, A., Simbolon, D., Rakhmawati, A., & Atun, S. (2024). Lithogeochemical characteristics and potential hyperaccumulator identification as phytomining agent at the Ratatotok gold mine, Indonesia. Journal of Degraded and Mining Lands Management, 11(2), 5251–5261.

Aziz, M. (2014). Model pertambangan emas rakyat dan pengelolaan lingkungan tambang di wilayah Desa Paningkaban, Kecamatan Gumelar, Kabupaten Banyumas, Jawa Tengah. Dinamika Rekayasa, 10(1), 20–28.

Borolla, S. M., Mariwy, A., & Manuhutu, J. (2019). Fitoremediasi tanah tercemar logam berat merkuri (Hg) menggunakan tumbuhan kersen (Muntingia calabura L) dengan sistem reaktor. Molluca Journal of Chemistry Education, 9(2), 78–89.

Dulanlebit, Y. H., Unwakoly, S., & Sangadji, R. P. (2021). Studi potensi Pteris vitata, Amaranthus spinosus, Ipomoea reptanspoir sebagai fitoremediator tanah tercemar merkuri (Hg). Molluca Journal of Chemistry Education, 11(1), 32–38.

Ghassani, K. N., & Titah, H. S. (2022). Kajian fitoremediasi untuk rehabilitasi lahan pertanian akibat tercemar limbah industri pertambangan emas. Jurnal Teknik ITS, 11(1), F8–F14.

Hadi, A. N. K. R., & Purnomo, T. (2022). Potensi Cordyline fructicosa dan Sanseviera trifasciata sebagai agen penyerapan logam berat Cd pada tanah. LenteraBio: Berkala Ilmiah Biologi, 11(3), 359–368.

Hasanah, U. N. (2022a). Analisis dampak kegiatan pertambangan emas terhadap lingkungan fisik di Desa Paningkaban Kecamatan Gumelar Kabupaten Banyumas tahun 2021. Indonesian Journal of Environment and Disaster, 1(1), 18–23. https://doi.org/10.20961/ijed.v1i1.64

Hasanah, U. N. (2022b). Analisis dampak kegiatan pertambangan emas terhadap lingkungan fisik di Desa Paningkaban Kecamatan Gumelar Kabupaten Banyumas tahun 2021. Indonesian Journal of Environment and Disaster, 1(1), 18–23.

Hidayati, N., Syarif, F., & Juhaeti, T. (2016). Pemanfaatan Salvinia molesta D.S. Mitchell, akumulator merkuri di sawah tercemar limbah penambangan emas. Jurnal Teknologi Lingkungan, 10(3), 249–256.

Irhamni, I., Pandia, S., Purba, E., & Hasan, W. (2017). Kajian akumulator beberapa tumbuhan air dalam menyerap logam berat secara fitoremediasi. Jurnal Serambi Engineering, 1(2).

Ismail, I., Mangesa, R., & Irsan, I. (2020). Bioakumulasi logam berat merkuri (Hg) pada mangrove jenis Rhizophora mucronata di Teluk Kayeli Kabupaten Buru. BIOSEL (Biology Science and Education): Jurnal Penelitian Science dan Pendidikan, 9(2), 139–153.

Kafle, A., Timilsina, A., Gautam, A., Adhikari, K., Bhattarai, A., & Aryal, N. (2022). Phytoremediation: Mechanisms, plant selection and enhancement by natural and synthetic agents. Environmental Advances, 8, 1–18.

Karyati, K., Putri, R. O., & Syafrudin, M. (2018). Suhu dan kelembaban tanah pada lahan revegetasi pasca tambang di PT Adimitra Baratama Nusantara, Provinsi Kalimantan Timur. AGRIFOR: Jurnal Ilmu Pertanian dan Kehutanan, 17(1), 103–114.

Kurniawan, B., Duryat, D., Riniarti, M., & Yuwono, S. B. (2019). Kemampuan adaptasi tanaman mahoni (Swietenia macrophylla) terhadap cemaran merkuri pada tailing penambangan emas skala kecil: Adaptation ability of mahogany (Swietenia macrophylla) against mercury contamination from artisanal and small-scale gold mining. Jurnal Sylva Lestari, 7(3), 359–369.

Nugroho, H. (2020). Pandemi Covid-19: Tinjau ulang kebijakan mengenai PETI (pertambangan tanpa izin) di Indonesia. Jurnal Perencanaan Pembangunan: The Indonesian Journal of Development Planning, 4(2), 117–125.

Nurlina, S. S., & Ruslan, U. (2016). Akumulasi logam berat besi pada kiapu dari air sekitar workshop UNHAS. Prosiding Seminar Nasional From Basic Science to Comprehensive Education. Makassar: UIN Alauddin Makassar.

Obenu, A., & Kebumian, L. D. (2019). Fitoremediasi tanah tercemar aluminium menggunakan Scirpus grossus, Typha angustifolia dan bioaugmentasi Vibrio alginolyticus. Surabaya: Institut Teknologi Sepuluh Nopember.

Rahmadanti, M. S., Pramana, A., Okalia, D., & Wahyudi, W. (2019). Uji karakteristik kompos (pH, tekstur, bau) pada berbagai kombinasi tandan kosong kelapa sawit (TKKS) dan kotoran sapi menggunakan mikroorganisme selulotik (MOS). JITEK (Jurnal Ilmiah Teknosains), 5(2), 105–112.

Rahman, F., Ilfan, F., Rodhiyah, Z., & Ihsan, M. (2021). Potensi tumbuhan lokal sebagai agen fitoremediasi untuk menurunkan kadar logam merkuri (Hg) pada lahan bekas penambangan emas tanpa izin di Kabupaten Sarolangun, Jambi. Envirotek: Jurnal Ilmiah Teknik Lingkungan, 13(2), 48–54.

Suharno, et al. (2023). Buku ajar pengantar Bioremediasi. Deepublish.

Tuheteru, F. D., Arif, A., & Rajab, M. F. (2017). Potential of nickel (Ni) phytoremediation of adaptive species on revegetation land, PT. Vale Indonesia (Tbk), Pomalaa Site Kolaka Regency. Jurnal Wasian, 4(2), 89–96.

Ulimma, R. (2016). Potensi tanaman hias dalam meremediasi tanah tercemar logam merkuri (Hg) (Studi kasus: Tailing Mandor). Jurnal Teknologi Lingkungan Lahan Basah, 4(1).

Witasari, W. S., Sa'diyah, K., & Hidayatulloh, M. (2021). Pengaruh jenis komposter dan waktu pengomposan terhadap pembuatan pupuk kompos dari activated sludge limbah industri bioetanol. Jurnal Teknik Kimia dan Lingkungan, 5(1), 31–40. https://doi.org/10.33795/jtkl.v5i1.209