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Phytoremediation Methods for Managing Lead (Pb) Contaminated Soil: A Literature Review

Emil Salim Kahmi Leka[1*], Tedy Agung Cahyadi[1], Rika Ernawati[1], Eddy Winarno[1]

Master of ining Engineering Study Program, Department of Mining Engineering,
Faculty of Mineral Technology and Energy, Universitas Pembangunan Nasional "Veteran" Yogyakarta
**Corresponding author: lekaemil103@gmail.com*

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ABSTRACT

In addressing the issue of heavy metal contamination, current reviews mainly focus on remediation through plants. Phytoremediation, a promising technology involving the use of plants to absorb heavy metals from the soil and eliminate contaminants by harvesting the plant parts above ground, has garnered significant attention due to its cost-effectiveness and environmental friendliness. The objective of this research, based on a literature review, is to determine whether there is a reduction in lead (Pb) concentration in the soil using phytoremediation methods and to assess the efficiency of plants in absorbing lead (Pb) from the soil. Based on the review of 5 plants from previous studies, some plants have shown significant and efficient effects in assisting the absorption of lead (Pb) content in the soil. Calotropis gigantea (95.88%) and Sphenoclea zeylanica Gaertn (92.43%) are identified as suitable plants for applying the phytoremediation method due to their fast absorption processes, ease of application, and availability

INTRODUCTION

The concentration of lead (Pb) in soil has nearly tripled due to human activities such as mining, smelting, manufacturing, waste disposal, and the increasing urbanization and industrialization. Pb primarily accumulates in the topsoil (Kumar et al., 2022). The resulting soil Pb pollution poses significant risks to human health, agricultural product safety, and the environment. Conventional remediation techniques for addressing Pb contamination in soil, such as excavation, electrokinetic remediation, soil leaching, and stabilization, can be costly or ineffective, making them unsuitable for large-scale applications (Rehman et al., 2023).

Lead (Pb), a common contaminant, can have negative impacts on both the environment and human health (García-Delgado et al., 2015b; Rigas et al., 2009; Sehube et al., 2017). Due to the challenges posed by the simultaneous presence of chemicals with disparate properties, this type of contamination, often

CONTACT Emil Salim Kahmi Leka | lekaemil103@gmail.com | Mining Engineering Study Program, Department of Mining Engineering, Faculty of Mineral and Energy Technology, Universitas Pembangunan Nasional "Veteran" Yogyakarta

referred to as mixed contamination, frequently hinders remediation efforts (Cameselle and Gouveia, 2019; Polti et al., 2014). Anthropogenic activities, such as mining, increase the bioavailability of lead (Pb) and human exposure to it. Pb is naturally found in various geological processes, including hydrothermal vents, volcanic activity, atmospheric convection, and river erosion (Zhang et al., 2023). Mining, smelting, production and reuse processes, oil refineries, paints, pigments, electroplating, finishing, glassmaking, ceramics, the steel industry, coal, and power generation are just a few of the industries that release lead into the environment (Sevak et al., 2021; von Voithenberg et al., 2019). Pb contamination of the environment is a serious issue, and it is important to note that Pb waste does not only come from these industries. Pb-containing paints and lead-acid batteries used in the automotive sector also contribute to environmental pollution.

The remediation of contamination through plants is the primary focus of current research aimed at addressing the issue of heavy metal contamination. Phytoremediation, a promising method that uses plants to remove pollutants and absorb heavy metals from the soil by harvesting aboveground plant parts, has garnered significant attention due to its affordability and environmental friendliness (Dou et al., 2022). This method is appealing for controlling soil contamination because it not only utilizes natural plant processes but also contributes to environmental detoxification. However, the use of this technique is limited by factors such as the low bioavailability of lead in soil and the lack of Pb hyperaccumulator species (Shen et al., 2022; Egendorf et al., 2020). Therefore, selecting non-hyperaccumulator plants and implementing appropriate support measures could be a potential way to enhance the effectiveness of phytoremediation.

Hyperaccumulators are currently regarded as the optimal plants for phytoremediation; however, species classified as hyperaccumulators are limited in number and exhibit certain limitations, including reduced biomass and slow growth rates. As a result, researchers worldwide are exploring novel plant species suitable for the remediation of heavy metals through phytoremediation (Guo et al., 2018; Mahar et al., 2016; Cao et al., 2019; Willscher et al., 2017). Aquatic plants are an integral component of a complex ecosystem, capable of functioning as hyperaccumulators of heavy metals, thereby facilitating the remediation of heavy metal contaminants along with various other pollutants through the process of phytoremediation (Ali et al., 2020). Methodologies that employ plants to mitigate metallic concentrations rely on the absorption of these contaminants through the root systems, foliar structures, and aerial shoots of the plants. Aquatic plants play a crucial role in an intricate ecological framework, with the potential to serve as hyperaccumulators of heavy metals, thus aiding in the elimination of these contaminants as well as other pollutants through phytoremediation (Hu et al., 2015). The careful selection of appropriate plant species is the most critical factor for the successful implementation of phytoremediation strategies (Bali and Sidhu, 2021; Zhu et al., 2018).

METHODOLOGY

The procedure of this study begins with a comprehensive literature review on the types of plants that are effective in absorbing lead (Pb) through phytoremediation methods, with a focus on analyzing the characteristics of plants that have been proven in previous studies. Following this, an assessment of plant effectiveness is conducted based on criteria such as lead reduction efficiency, the time required for the phytoremediation process, and the sustainability of plant growth despite exposure to lead contamination. Based on the results of these studies and comparisons, researchers will draw conclusions about the most suitable plants to be used for lead removal in soil.

The stages of the research conducted are shown in **Figure 1.** below. This study is based on a literature review summarized from several scientific papers, both from national and international journals. A literature review is the process of in-depth analysis and evaluation of similar research conducted previously (Shuttleworth, 2009). The purpose of this research is to serve as a reference in examining the types of plants that are efficient in absorbing lead (Pb) from the soil using the phytoremediation method. The phases of the research conducted are as follows:

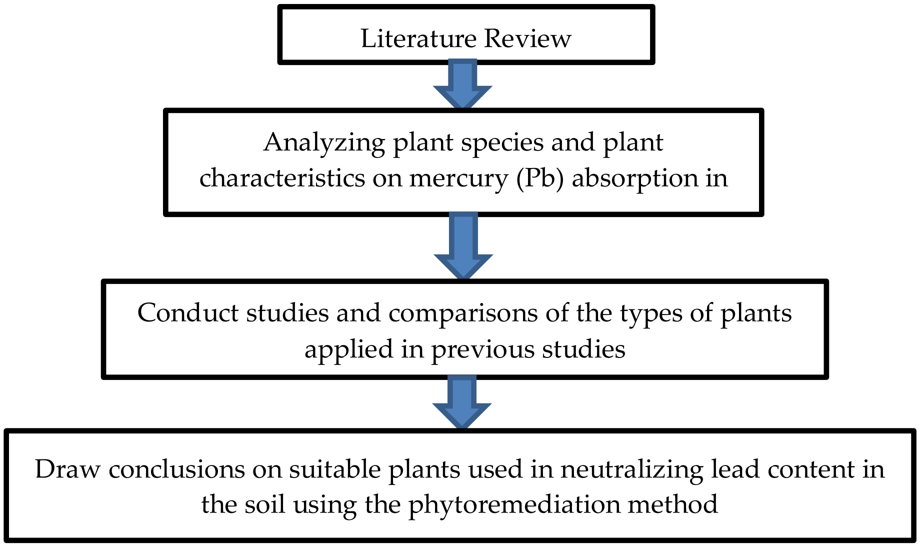

Figure 1. Research Stages

RESULT

Research has explained the need for plants in eliminating soil contaminated with heavy metal substances. Lead (Pb) is one of the heavy metal pollutants and is a naturally occurring element that frequently contaminates the environment and is highly toxic. Efforts to remove lead from contaminated soil have been conducted in various locations using the phytoremediation technique. Phytoremediation is one of the bioremediation methods that can be used as an alternative solution for the heavy metal remediation process. Phytoremediation is a practical, efficient, and environmentally friendly green technology that involves the use of metal-accumulating plants to remove toxic metals, including radionuclides and organic contaminants, from polluted soil and water (Raskin et al., 1997). Plants play a crucial role in eliminating contaminants from the environment, achieving their detoxification effect. Three main phytoremediation processes can be identified based on the different properties of the plants: phytoaccumulation, phytostabilization, and phytovolatilization (Marques et al., 2009). The following plants can be used to remove lead content from soil, based on previous research, among others:

Table 1. Phytoremediation Plant Species

Researcher Name	Plant Type	Absorption Time (Day)	Treatment	Decrease in Lead Level
Rony Irawanto , Anjar Aris Munandar	*Ceratophyllum demersum*	14	83 gr	85,1%
L. Indah Murwani Yulianti	*Calotropis gigantean*	28	700 mg/l	95,88%
Rhenny Ratnawati , Risna Dwi Fatmasari	*Sansevieria trifasciata*	30	200 mg	81,08%
Juhriah, Nur Fadila, Mutmainnah dan Dian Islamiah	*Zinnia elegans (Jacq.) Kuntze*	84	100 gr	50%
Ninik Triayu Susparini , Fathur Rohman , Heny Hindriani	*Sphenoclea zeylanica Gaertn*	6	150 gr	92,43%

The research presented in this table examines the effectiveness of several plant species in reducing lead (Pb) levels from contaminated media. Each plant has different uptake times as well as varying treatment dosages, which affect their efficiency in absorbing lead.

The plant successfully reduced lead levels by 85.1% within 14 days with 83 grams of treatment. The effectiveness was quite high, which shows that aquatic plants such as Ceratophyllum demersum can be a good choice for lead remediation in aquatic environments. Although the reduction in lead levels did not reach 100%, this result was very significant in a relatively short time.

With a sorption time of 28 days and 700 mg/l treatment, Calotropis gigantea showed a very high lead reduction of 95.88%. This plant has a remarkable ability to absorb lead, making it a potential candidate for use in bioremediation of heavy metal-contaminated soil. Its advantage is its ability to survive in less than ideal environmental conditions, such as dry and nutrient-poor soils.

Sansevieria trifasciata, also known as tongue-in-law, successfully reduced lead levels by 81.08% after 30 days with 200 mg treatment. Although the lead reduction was not as great as the other plants in this study, Sansevieria trifasciata has other advantages such as ease of maintenance and the ability to survive in water shortage and poor soil conditions. Therefore, it also has the potential to be used in more extreme conditions.

The reduction in lead levels recorded in Zinnia elegans was 50% after 84 days with 100 grams of treatment. Although this reduction rate is lower than the other plants, Zinnia elegans shows that flowering plants can also have potential in remediation, although the results are slower and less efficient. The long time (84 days) may have contributed to the non-optimal lead reduction.

In this study, Sphenoclea zeylanica showed an excellent lead reduction ability of 92.43% in just 6 days with 150 grams of treatment. The high rate of lead reduction made this plant one of the most effective in this study. This shows the potential of this plant in rapid remediation of heavily polluted environments in a short time.

Overall, the main recommendation is to select plant species that best suit the specific environmental conditions and the level of lead contamination in the area. Plants with fast and efficient lead reduction, such as Sphenoclea zeylanica and Calotropis gigantea, are more suitable for remediation in heavily contaminated areas, while plants that are more resistant to extreme conditions, such as Sansevieria trifasciata, can be used in areas with limited resources. Ceratophyllum demersum is excellent for aquatic environments, and Zinnia elegans can be selected for long-term remediation projects in combination with other plants.

The following is a table of the advantages and disadvantages of plant species in the absorption of lead metal in the soil.

Table 2. Excess and Shortage of Plants

Type of Plant	Excess	Shortage
Ceratophyllum demersum	1. Effective in absorbing various heavy metals from soil, including lead. 2. These plants can absorb heavy metals relatively quickly, helping to reduce metal pollution in a short period of time. 3. This plant helps in the absorption of excess nutrients.	1. Limited capability compared to some other crops 2. These plants may not be able to effectively remove all types of heavy metals or other contaminants, depending on the concentration and type of pollutants.

Calotropis gigantean	1. These plants can help reduce lead concentrations in contaminated environments. 2. These plants have relatively fast growth, which can help the soil remediation process in a short time compared to some other plants. 3. The plant is drought-resistant and can grow in a wide range of soil conditions, including contaminated or infertile soils	1. Calotropis gigantea plants contain toxic compounds that can be harmful if ingested by humans or animals. This can be a problem in the context of using the plant for soil rehabilitation near residential areas 2. It may not grow well in very high humidity conditions or waterlogged soils, which may limit its application in some environments.
Sansevieria trifasciata	1. Sansevieria trifasciata is known to absorb several types of air pollutants such as formaldehyde, benzene, and trichloroethylene. While its ability to absorb heavy metals such as lead from the soil is not well known, its ability to improve air quality in enclosed spaces is a plus. 2. It can survive low lighting and drought conditions, which makes it easy to maintain in a variety of indoor environments, including spaces with potential contamination. 3. It can survive low lighting and drought conditions, which makes it easy to maintain in a variety of indoor environments, including spaces with potential contamination 4. Sansevieria trifasciata is easy to grow and maintain, requires no special care, and can grow well in a wide range of soil conditions, including poor or contaminated soil. It does not require a rich substrate to grow and can function in a wide range of soil conditions.	1. Its ability to absorb lead from the soil is not as strong as some other plants. 2. Sorption of heavy metals such as lead by Sansevieria trifasciata may be less significant
Zinnia elegans (Jacq.) Kuntze	1. It grows quickly, which means it can start absorbing heavy metals immediately after planting, providing faster results than some other crops. 2. The plant can grow in a wide range of soil conditions, including soils that may be contaminated with heavy metals, making it flexible in use	Zinnia elegans may not be as effective as some hyperaccumulator plants in absorbing heavy metals. Its ability to lower lead concentrations in soil may not be as strong as plants specifically designed for soil remediation.
Sphenoclea zeylanica Gaertn	1. Sphenoclea zeylanica has the ability to absorb heavy metals from the soil. 2. This plant has relatively fast growth. 3. Sphenoclea zeylanica can grow in a variety of soil conditions, including soils that may be contaminated with heavy metals.	1. Although Sphenoclea zeylanica can absorb heavy metals, its ability may not be as strong as some other hyperaccumulator plants. 2. This plant requires wet or humid conditions to grow well. In a dry or less humid environment, plant growth and metal uptake effectiveness may be affected.

CONCLUSION

Based on the results, the two plants with the highest lead (Pb) reduction were *Calotropis gigantea* and *Sphenoclea zeylanica*. *Calotropis gigantea* showed a 95.88% decrease in lead levels within 28 days with a 700 mg/l treatment, making it highly effective for the bioremediation of heavy metal-contaminated soil, particularly in less-than-ideal conditions such as dry and nutrient-poor soils. Meanwhile, *Sphenoclea zeylanica* demonstrated an impressive 92.43% reduction in just 6 days with a 150-gram treatment, making it an excellent choice for rapid remediation of heavily contaminated soils. Both plants were highly effective in reducing lead levels in a short period, with *Sphenoclea zeylanica* being more suitable for emergency remediation and *Calotropis gigantea* being better for more challenging soil conditions.

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