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Phytoremediation of lead on arid land: A review

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Abstract. Lead (Pb) is one of the non-essential heavy metals which can cause soil pollution. Lead within the soil can change the nature of soil. Meanwhile, land is one of the important supporting factors in the life of living things. One technique that can restore the polluted environment by Pb is phytoremediation method. Phytoremediation is a process that utilizes a variety of plants to reduce and/or to remove contaminants in the soil. This paper aimed to discuss various phytoremediation mechanisms of Pb and its potential as a remediation technique that utilizes the ability of plants to remove heavy metals from polluted soils.

1. Introduction

Soil pollution is an environmental pollution occuring due to the contamination of chemicals to the soil that can change the natural soil environment. Meanwhile, soil is one of the important supporting factors in the ecological cycle. However, soil pollution caused by natural factors and human activities is very difficult to avoid [1,2,3,4] including heavy metals contamination. Heavy metals are considered a group of pollutants because they are non-degradable [5]. Lead (Pb) is a kind of heavy metals that can be potentially toxic in excess concentrated [4,6,7].

Lead is a non-essential heavy metal which is toxic for organisms [8]. These toxicities are cumulative meaning the nature of the toxic will arise if accumulated in a large quantity into an organism [9,10,11,12,13].

Phytoremediation is a method to remediate the environment by Pb contamination. Phytoremediation is a technique utilizing a variety of plants to remove and destroy contaminants in soil or water [3,14,15,16,17]. This method has been considered as a cheap and effective technology. Because of its reliability, phytoremediation can replace other technologies that are considered expensive and not optimum in removing heavy metals from the environment [18]. Therefore, this paper aimed to analyse the ability and efficiency of phytoremediation techniques to remove Pb on arid land.

2. Lead (Pb)

Lead is a heavy metal naturally found in the earth crust. It originated from human activities. In fact, the number of Lead from anthropogenic activity is 300 times higher than lithogenic Pb. Lead has an atomic number 82, an atomic weight of 207.19, and a specific gravity of 11.34, a bluish color or silvery gray with a melting point of 327.5°C and a boiling point at atmospheric pressure of 1740°C

[18]. It has a low melting point, is easily formed, and has active chemical properties, so that it can be used to coat the metal to avoid rusting [9, 10,11,12,13].

Lead is a compound that is highly toxic to humans if it is contaminated in a large quantity. It has properties that cannot be decomposed naturally that is very dangerous in biological systems. Lead also has properties that are very difficult to dissolve in the environment. Therefore, if Pb enters the body in a large concentration, it will cause serious health problems for humans such as brain damage and mental retardation. In a study in the USA, where 78% of homes had soil-lead levels higher than 0.5 µg/g, it was estimated that a child eating only half a gram of soil would ingest 250 µg of lead, almost twice the maximum intake limit per day [19,20]. In addition, Pb is not only dangerous for humans, but also dangerous for microorganisms, spills, and animals [21].

The contamination of Pb into the human body can go through air, water, and soil. Lead is considered safe in the soil by a threshold of 0.07 µg/g. Lead in the soil is mostly sourced from vehicles. Several studies reported that areas near highways in urban environments have experienced serious pollution. Furthermore, Pb on the road will be contaminated to the surrounding land including agricultural land. In this case, remediation is needed to reduce Pb from the soil. Various techniques have been proposed including phytoremediation techniques. The term phytoremediation comes from Greek in which “phyto” means plant and “remediation” means to repair, to reduce, or to restore. Phytoremediation is the use of plants to remediate, reduce, or restore polluted lands [3,14,15,16,17,22]. As a result, the objective of this paper is describing the Pb phytoremediation technique on arid land.

3. Phytoremediation

Phytoremediation is defined as a technology that utilizes certain plants to restore a contaminated environment from harmful pollutants to improve the quality of the environment. Phytoremediation can be classified based on the process of absorption and removal of metals, namely phytoextraction, rhizofiltration, phytodegradation, phytostabilization and phytovolatilization [23,24,25]. The process of Pb absorption is shown on figure 1.

3.1. Phytoextraction

Phytoextraction or phytoaccumulation is the absorption of heavy metals by plant roots accumulating heavy metals that have been absorbed into plant parts such as roots, stems, and leaves [22,25]. This method is widely used for metal waste [27]. In this method, the root component is very important to increase the absorption capacity of plants in the waste in the environment [28]. The process of absorption of heavy metals by plants can be seen in the scheme of figure 2 [29].

3.2. Rhizofiltration

Rhizofiltration is a process of utilizing the ability of plant roots to absorb, precipitate, and accumulate metals from waste streams [24,25]. Rhizobacteria can be used to deal with heavy metals contaminated land, especially Pb so that land can still be used for agricultural activities that are safe for human health and the environment. Rhizobacteria can increase Pb absorption in plant tissue (phytoextraction) and some others can reduce absorption (phytostabilization) [30]. Rhizobacteria has a mechanism that can cause changes in the availability of metal elements in the soil to become whether more easily or difficult to be absorbed by plants. Rhizobacteria can interact symbiotically with roots to increase the metal absorption potential [31].

3.3. Phytodegradation

Phytodegradation is the decomposition or metabolism of contaminants (heavy metals) in waste by utilizing the activity of microbes and enzymes such as dehagenase and oxygenation around the roots of plants [32]. The role of rhizosphere bacteria (rhizobacteria) found in roots can break down organic or inorganic compounds [33]. Rhizobacteria plays a major role in plant growth in phytoremediation techniques [34,35,36,37,38,39]. Bacteria can be found living on the surface of plants or in plants [40]. Most microorganisms that live on the surface of plants are near the root surface (rhizoplane) and narrow zones around the root (rhizosphere) or on the surface of leaves (phyllosphere). The rhizosphere is defined as a narrow zone of nutrient-rich soil that surrounds plant roots and is influenced by root exudates and microbial activity. Beneficial bacteria can produce phytohormones that stimulate plant growth and development and encourage tolerance to environmental stresses [41,42].

3.4. Phytostabilization

Phytostabilization is the ability of plants to excrete certain chemical compounds to immobilize heavy metals in the root region (rhizosphere) or attach certain contaminants to roots that cannot be absorbed into the stems of plants. These substances will stick closely to the root (stable) and will not be carried away by the flow of water [43,44]. This method can help rebuild vegetation in locations that are contaminated with high metal concentrations [45].

3.5. Phytovolatilization

Phytovolatilization is a process when plant absorbs heavy metal contaminants and releases them (transpiration) into the air through the leaves and has been degraded beforehand, so that they are no longer dangerous when released into the air [46].

3.6. Phytotransformation

Phytotransformation is the absorption of heavy metal contaminants by plants to decompose contaminants that have complex molecular chains into harmless materials with molecular arrangements that are simpler and useful for the plant. Phytotransformation process can occur in roots, stems, and leaves and can occur around the roots with the help of enzymes released by plants to accelerate the degradation process [24,25].

The process of decomposition of heavy metals in the phytoremediation process depends on the interaction between the soil, heavy metals, bacteria, and plants. This complex interaction is influenced by various factors, such as plant characteristics and activities, rhizobacteria, climatic conditions, and soil properties

One of the requirements in phytoremediation is that hyperaccumulator plants must be able to grow in any land condition, have a tolerance level of contaminants, be able to remediate more than one pollutant, grow fast and be able to consume large amounts of water in a short time. Table 1 shows the species that have been used in phytoremediation.

From the reports in table 1, the right plants to be applied in phytoremediation techniques are (i) selecting plant species that are able to grow quickly in high toxic environmental conditions, (ii) able to consume large amounts of water in a short time and (iii) able to decontaminate or remediate more than one pollutant and has a high level of resistance to pollutants. The types of plants that are used efficiently are spinach plants, grasses and sunflowers. In addition to choosing the right plant species, the addition of chelation agents as the efforts to increase the absorption and ability of plants to accumulate Pb metal. One of the most powerful and commonly used chelating agents is ethylene diamine tetraacetic acid (EDTA), which forms complexes with many metal contaminants in the natural environment [47].

Ethylene diamine tetraacetic acid is a chelation agent that is capable of chelating heavy metals in the soil. The addition of EDTA chelation agents in plants can increase accumulation in several heavy metals including Pb [48,49,50,51,52]. Ethylene diamine tetraacetic acid is well known for its excellent ability to recover metals from the soil (25-80%) [53,54]. Nascimento et al., 2006 investigated that the effects of EDTA chelation agents were effective in reducing Pb concentrations in soils. [56] explained that the application of EDTA with sunflower plants *Helianthus annuus L.* is able to increase the accumulation of Pb more than (80%) which is cultivated in the hydroponic system. A research conducted by [57] also showed that EDTA applications with different plant species, such as Cannabis sativa, Medicago sativa, Zea mays and Vulghum Sorghum are able to accumulate Pb, Cd and Zn. The use of EDTA chelation agents is also able to accumulate Pb contaminated soil by more than (81%) [58].

Besides EDTA, the adding of compost is also a source of nutrients for plant growth. The use of compost can increase plant growth and biomass. Nutrients provided by compost can increase plant growth and can accelerate the absorption of metals into plants [66]. Further, compost has a role in improving soil aggregate stability, increasing water absorption, and increasing soil cation exchange capacity [67]. Cow dung extract and poultry dung extract are recommended to increase the metals accumulated by plants because chelant is able to increase the biomass produced by plants [68,69].

Compared with other techniques, phytoremediation has advantages and disadvantages [70,71,72,73,74,75,76] are shown in table 2.

Table 2. Strengths and weaknesses of the use of phytoremediation techniques.

No.	Strengths	Weaknesses
1.	The safest way to remediate the environment is by using plants	Requires a long time
2.	Plants are easily controlled for growth	Waste environmental characteristics
3.	Maintaining the natural state of the environment	Level of toxicity
4.	Operating costs are relatively cheap	Suitability of plants in the waste environment
5.	Plants are easy to breed	Harmful if plants are eaten by animals or insects
6.	Plants are easily controlled for growth	

From the weaknesses of phytoremediation described in table 1, it can be concluded that plant species for phytoremediation must be chosen to ensure that roots can expand throughout the contaminated zone. In addition, plant selection in principle must follow application requirements, contaminants of concern, and potential for growth in contaminated locations. Further, vegetation must be fast growing, strong, easy to plant and maintain [77].

Some engineering processes that are currently used to clean up heavy metal pollution are not only expensive but also damage the environment, causing adverse impacts on the ecosystem. Now, researchers have established a cost-effective and environmentally friendly technology that includes the use of plants/microorganisms to clean up contaminated environments [49]. Various heavy metal decontamination techniques and their advantages and disadvantages are presented in table 3.

It is possible that applying two or more combined methods can minimize obstacles and achieve higher levels of decontamination. The sequential treatment of one of the physical, chemical, and biological methods may be more effective in phytoremediation. For example, methods such as coagulation followed by photocatalysis and then phytoextraction not only save time but can also help increase the efficiency of contaminant removal. Phytoremediation with soil is considered more suitable for the microorganism/plant decontamination process. However, this article merely focuses on phytoremediation techniques having the potential for economically efficient remediation, contaminants turning into less toxic substances, applicable to soil, sediment, mud, accelerating the degradation process and being environmentally friendly.

Phytoremediation has the potential to be applied to various types of substances, including the most severe environmental pollutants such as arsenic contamination in installed chemical weapons land [78]. Phytoremediation is a remediation technology that offers the lowest cost compared to the cost of engineering-based methods. The use of phytoremediation can also provide benefits from an economic perspective, where phytoremediation can progressively improve soil quality for plants [79].

Therefore, phytoremediation techniques are needed in the future considering the intense increase of pollution cases each year especially in Indonesia which has a density of motorized vehicles. Meanwhile, the carrying capacity of land and water resources has declined over time. At

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least 35% of Indonesia's territory has been converted to mining areas. This naturally will change Indonesia's landscape and make the potential for pollution even greater in the future [85].

4. Conclusions

In general, Pb phytoremediation on arid land technique has advantages and disadvantages. However, the overall review can help us understand how to choose a process to remediate certain heavy metals based on the duration and efficiency and also able to identify plants that are often used for phytoremediation. Pb phytoremediation is an effective way to restore arid land. Phytoremediation technique has several advantages compared to conventional technology that is commonly used. It is relatively safer for the environment due to the plant's use and natural environment maintenance, and it has relatively low operational costs.

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