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Research Article

OVERVIEW OF HEAVY METAL REMEDIATION IN WATER USING PHYTOREMEDIATION TECHNOLOGY: EVALUATION, POTENTIAL, AND CHALLENGES

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ABSTRACT

Vietnam is facing serious environmental challenges due to uncontrolled industrial and agricultural development, leading to an increasing contamination of heavy metals in water. Heavy metals such as lead (Pb), cadmium (Cd), mercury (Hg), and zinc (Zn) from mining activities, industrial production, and chemical fertilizer use have infiltrated groundwater and surface water systems, causing serious health and ecosystem consequences. Traditional remediation methods such as chemical use and physical technology often require high costs and pose risks of causing additional environmental problems. In this context, research and application of environmentally friendly pollution treatment methods, especially using plants (phytoremediation), are becoming a potential and sustainable solution. Phytoremediation not only efficiently removes heavy metals from the water environment but also improves the quality of the living environment through ecosystem restoration and maintenance. However, the application of phytoremediation in Vietnam is still in the experimental stage and requires further research to evaluate practical effectiveness and identify suitable plant species for local conditions. Therefore, implementing research on using plants in treating heavy metal pollution in water not only has scientific significance but also contributes significantly to environmental protection and sustainable development in Vietnam.

Keywords: Phytoremediation, heavy metals, metal-accumlating plans

INTRODUCTION

Phytoremediation is an environmental remediation method that uses plants to remove, stabilize, or degrade pollutants, including heavy metals, in water environments. The main mechanisms of phytoremediation include: phytoextraction, where plants absorb heavy metals from water environments through roots and accumulate them in various parts of the plant; phytostabilization, where plants reduce the movement of heavy metals by absorbing them into roots and preventing dispersion; phytodegradation, where plants secrete enzymes to degrade organic pollutants into less toxic substances; and rhizofiltration, where plant roots absorb and filter heavy metals from water. Thanks to these mechanisms, phytoremediation can help clean and improve the quality of water environments naturally and sustainably.

Recent advances in phytoremediation:

In recent years, many plant species have been successfully researched and used in treating heavy metals in water. Some typical plant species with efficient absorption and accumulation of heavy metals include: Pteris vittata, Vetiveria zizanioides, Eichhornia crassipes, Ipomoea aquatica, and Salix spp. Pteris vittata has been demonstrated to effectively absorb metals such as lead (Pb) and arsenic (As); Vetiveria zizanioides stands out with its stabilization and absorption of heavy metals in water and soil; Eichhornia crassipes has rapid growth and the ability to accumulate heavy metals such as cadmium (Cd) and mercury (Hg); Ipomoea aquatica has the ability to absorb metals such as lead and zinc (Zn); and Salix spp. is known for its ability to process copper (Cu) and zinc. These studies have opened up great potential for the application of phytoremediation technology in treating heavy metal pollution, thereby reducing costs and negative environmental impacts.

Evaluation of phytoremediation effectiveness:

Phytoremediation technology is becoming a promising method for treating heavy metals in water, but its effectiveness is still being evaluated and compared with other traditional methods. Some studies have reported the success of this technology in removing heavy metals from water and soil, but further research is needed to understand the mechanisms of action and long-term effects of various plant species. Evaluating the effectiveness of phytoremediation requires careful observation and assessment of factors such as metal removal rate, soil reuse ability, impact on local ecosystems, and implementation costs. Advanced studies need to be conducted to provide specific data and comprehensive analysis of the economic and environmental efficiency of phytoremediation technology in treating heavy metals.

In the United States, peanuts (Arachis hypogaea) have been used to remove heavy metals such as lead and cadmium from contaminated soil in industrial areas. In France, oak trees (Quercus spp.) and ferns (Salix spp.) have been used to treat heavy metal pollution in soil. In China, Arabidopsis halleri and Vetiveria zizanioides have been used to treat heavy metal pollution in soil. According to the research results of the author group, the clover plant Trifolium alexandrinum, grown in a greenhouse, has been shown to absorb heavy metals such as Zn, Pb, Cu, and Cd from the soil, with the order of heavy metal absorption being

Zn>Pb>Cu>Cd. This research also demonstrates the benefits of using Trifolium alexandrinum for phytoremediation, as it produces significant biomass, has a short growth cycle, is resistant to current environmental conditions and climates, and provides multiple harvests in a single growth stage.

Sunflower plants have also been studied for heavy metal remediation in soil. According to [Adesodun,2010], two sunflower species, Tithonia diversifolia and Helianthus annuus, have been studied; Tithonia diversifolia significantly absorbed lead concentrations in aboveground biomass compared to root concentrations. Concentrations in leaves were 87.3, 71.3, and 71.5 mg/kg after 4, 6, and 8 weeks of planting, respectively. In roots, it was 99.4 mg/kg, 97.4 mg/g, and 77.7 mg/kg, while 79.3, 77.8, and 60.7 mg/kg were observed in plant stems after 4, 6, and 8 weeks. The observations with H. annuus followed a similar pattern to T. diversifolia, showing significant ($p < 0.05$) accumulation of lead in aboveground biomass. Results from soil contaminated with zinc nitrate show significant ($p < 0.05$) zinc accumulation in aboveground parts of T. diversifolia and H. annuus compared to the roots. However, the highest accumulation of Zn was observed in the leaves. The mobility and enrichment factors of Pb and Zn with these plant species were both greater than 1, indicating that these metals move more easily within these plants. In summary, this study demonstrates that these two sunflower species accumulated significant concentrations of lead and zinc in the above-ground parts (leaves and stems) after 4 weeks of experimentation, decreasing over time. This implies that the efficiency of these plants in soil remediation is high in the early stages of their growth process.

In Vietnam, numerous studies have demonstrated the effectiveness of phytoremediation technology in treating heavy metal pollution in water. The use of maize (Zea mays), bamboo (Bambusa vulgaris), and hyperaccumulator plants in areas contaminated with lead and cadmium has shown promising results. Vetiver grass has been used to treat wastewater in construction projects. Mangroves have been widely planted in coastal areas to protect shorelines and mangrove forests.

In a study using Syngonium podophyllum Schott to remove arsenic pollution in mining areas, researcher Bùi Văn Năng and colleagues concluded that the plant showed robust growth and development in arsenic-contaminated soil, with significant arsenic removal capabilities. Another study by Bùi Thị Kim Anh investigated arsenic treatment using ferns, revealing Pteris vittata and Pityrogramma calomelanos' high arsenic accumulation in above-ground biomass. These ferns also demonstrated resilience in soil with high arsenic levels and processed other metals like cadmium, lead, and zinc when present at lower concentrations in the soil. The optimal harvest time for these plants was found to be 3-4 months, indicating practical application feasibility.

Challenges in implementing phytoremediation technology persist despite its potential benefits. One significant challenge is scaling up its application across diverse geographical conditions. Extensive research is needed to optimize environmental conditions and select the most suitable plant species for specific environments. Additionally, cost considerations pose a significant challenge. Comparing the deployment and maintenance costs of phytoremediation technology with other treatment methods is essential to ensure its economic viability. Environmental and human health risk management is also critical. It must be ensured that phytoremediation does not pose negative impacts on local ecosystems or community health. Overcoming these challenges requires close collaboration between researchers, businesses, governments, and other stakeholders to advance research and application of phytoremediation technology in heavy metal treatment. Continuous investment in research and development is necessary to leverage the latest advancements in the field and optimize process efficiency and sustainability.

In Vietnam, applying phytoremediation technology to treat heavy metal pollution in water faces specific challenges. Firstly, environmental pollution is worsening, especially in industrial and urban areas, primarily due to industrial wastewater containing lead, mercury, and cadmium, along with runoff from manufacturing areas. Finding suitable land for implementing projects treating heavy metal-containing wastewater is another challenge, particularly in urban areas where suitable space may face competition from other development targets.

Moreover, securing funding for these projects presents a significant challenge. For many organizations and businesses in Vietnam, accessing sufficient funding to implement projects treating heavy metal-containing wastewater remains a major difficulty. Lastly, managing and controlling projects also pose numerous challenges. While environmental management systems are improving, there are still limitations in enforcing and monitoring regulations related to heavy metal-containing wastewater treatment. This may entail risks in ensuring that treatment projects are implemented and operated effectively, complying with environmental regulations.

CONCLUSIONS

Phytoremediation is a promising and environmentally friendly method for treating heavy metal pollution in water. Despite its many benefits, the method still faces challenges related to plant growth, treatment duration, and post-treatment management. To enhance the effectiveness of phytoremediation, continued research and development of new plant species and supportive techniques are necessary, along with the formulation of sensible management policies and strategies.

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