

Phytoremediation of heavy metal polluted soil and water in Vietnam

Sử dụng thực vật để xử lý ô nhiễm kim loại nặng trong đất và nước tại Việt Nam

Research article

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Phytoremediation has been intensively studied during the past decade due to its cost-effectiveness and environmental harmonies. Most of the studies on treatment of heavy metal pollution in soil and water by plant species have been done in developed countries but are limited in Vietnam. In this study, we presented some research results of phytoremediation of polluted soils and water with heavy metals that were done by Institute of Environmental Technology for several last years. For treatment of heavy metal pollution in the water, some plants have great ability to accumulate heavy metals such as *Vetiveria zizanioides*, *Phragmites australis*, *Eichhornia crassipes*, *Pistia stratiotes*, *Ipomoea aquatica*, *Nypa fruticans* and *Enhydra fluctuans*. The heavy metal uptake into shoots and roots of 33 indigenous plant species in Thai Nguyen province was also determined. Two species of the plants investigated, *Pteris vittata* L. and *Pityrogramma calomelanos* L. were As hyperaccumulators, containing more than 0.1% As in their shoots while *Eleusine indica*, *Cynodon dactylon*, *Cyperus rotundus* and *Equisetum ramosissimum* accumulated very high Pb (0.15-0.65%) and Zn (0.22-1.56%) concentrations in their roots. Some experiments to clarify the potential of several plants as good candidates for phytoremediation of polluted soil by heavy metals were carried out in our institute.

*Phương pháp sử dụng thực vật để xử lý ô nhiễm đã được nghiên cứu nhiều trong thập kỷ qua do chi phí thấp và thân thiện với môi trường. Hầu hết các nghiên cứu về xử lý ô nhiễm kim loại nặng trong đất và nước bằng thực vật đã được thực hiện ở các nước phát triển nhưng ít có tại Việt Nam. Trong nghiên cứu này, chúng tôi giới thiệu một số kết quả dùng công nghệ thực vật để xử lý ô nhiễm kim loại nặng trong đất và nước tại Viện Công nghệ môi trường trong những năm gần đây. Đối với xử lý ô nhiễm kim loại nặng trong nước, một số thực vật có khả năng tích lũy tốt kim loại nặng như *Vetiveria zizanioides*, *Phragmites australis*, *Eichhornia crassipes*, *Pistia stratiotes*, *Ipomoea aquatica*, *Nypa fruticans* và *Enhydra fluctuans*. Sự hấp thụ và tích lũy kim loại nặng trong phần trên mặt đất và rễ của 33 loài thực vật bản địa tại Thái Nguyên cũng đã được xác định. Hai loài thực vật khảo sát là *Pteris vittata* và *Pityrogramma calomelanos* là những loài siêu tích lũy As, chứa hơn 0,1% As trong phần trên mặt đất của cây. *Eleusine indica*, *Cynodon dactylon*, *Cyperus rotundus* và *Equisetum ramosissimum* tích lũy Pb (0,15-0,65%) và Zn (0,22-1,56%) rất cao trong rễ. Một số thí nghiệm đánh giá tiềm năng của một số thực vật là đối tượng tốt cho xử lý ô nhiễm kim loại nặng trong đất đã được tiến hành trong phòng thí nghiệm của Viện Công nghệ môi trường.*

Keywords: phytoremediation, heavy metals, pollution, potential plant

1. Introduction

Pollution of soil and water is now a global problem and attracted attention of many countries due to its harmful effects with many aspects of environment and human life.

In Viet Nam, heavy metal pollution has been identified in many locations including urban areas as well as rural and mountainous ones. For example, in Hanoi, Van Dien industrial zone including Van Dien Batteries factory, Synthetic Paint factory, Van Dien Phosphate Company and also Orion Hanel industrial zone have high risk of

lead contamination (Le Hien Thao, 2004). The contamination in traditional villages is also an urgent problem. There are about 1450 traditional villages, based on the survey results of 52 typical villages, of which 100% surveyed villages had caused environmental pollution. Typically, the village recycling lead from batteries of Chi Dao commune, Van Lam district, Hung Yen province has 25 lead production units. Every day, this commune produces 10 tons of lead and generates about 1 ton of toxic dust (Dang Kim Chi et al., 2005). During the production, traditional villages released a large amount of significantly toxic chemicals into the environment via wastewater including many heavy metals such as Fe, Cr, Ni, Zn, and CN. Mineral exploiting and processing industry discharge highly toxic substances such as Cd, Pb, Zn, Cu, As (Le Van Thanh et al, 2004). The average As concentration in waste stone samples was of 5000 mg/kg, exceeding the allowable standard of heavy metal in the soil many times. The concentration of other heavy metals in the stone samples were also very high (Cu: 1260 mg/kg; Pb: 105 mg/kg; Cd: 0.5 mg/kg; Se: 17 mg/kg,...) (Tiberon mineral company, 2004). In some communes of Ha Nam province, 94.4% wells water samples had very high As concentration, with was exceeded national technical regulation on drinking water quality (Pham Hung Viet et al., 2004).

There are many methods for treating heavy metal pollution. Although physicochemical methods are effective, they are complex, expensive, not environmental friendly and difficult to be applied on a large scale. Phytoremediation is cost effective, environmental friendly and most suitable for developing countries (Ghosh et al., 2005). At present, more than 500 plant species of metal and metalloid hyperaccumulators have been reported in literatures (Hemen Sarma, 2011).

Phytoremediation of polluted soil and water is soon studied in many countries (Salt DE et al., 1995, Raskin I. et al., 1997, E. Lombi et al., 2001). However, in Viet Nam, this study has been started only in recent years and its practical application is still limited. Le Van Cat et al. (2008) researched on NH_4^+ and As removal capability from contaminated water by *Typha latifolia*, *Canna* and *Pennisetum purpureum*. Le Duc et al. (2005) studied on Pb uptake of *Ipomoea aquatica*, *Eichhornia crassipes* and *Brassica juncea*. Dang Thi An et al. (2007) identified heavy metal concentrations of some vegetables. Tran Kong Tau et al. (2005) indicated the accumulation ability of Cd and Zn in *Calendula officinalis*, *Acanthopanax aculeatus*. Tran Van Tua et al. (2008) researched on the tolerance and accumulation of Pb, Cd, Cr, Ni and Zn in some plant species. Diep Thi My Hanh et al. (2007) investigated the Pb accumulation of *Lantana camara*. In this paper, we present some research results of phytoremediation for polluted soil and water with heavy metals.

2. Materials and methods

2.1. Plant species



Figure 1. Plant species used in our experiments (a) *Pityrogramma calomelanos*; (b) *Pteris vittata*; (c) *Eleusine indica*; (d) *Brassica juncea*; (e) *Pennisetum purpureum*; (f) *Pistia stratiotes*; (g) *Eichhornia crassipes*; (h) *Vetiveria zizanioides*; (i) *Phragmites australis*.

3. Results and discussions

3.1. Heavy metal removal from water by plants

By experimental studies, we have demonstrated heavy metal uptake and accumulation in some aquatic plant species. For example, *Eichhornia crassipes* was likely to

absorb Pb, Cr, Ni, Zn and Fe in industrial waste water, *Nasturtium officinale* L. could remove Cr and Ni from electroplating wastewater. Meanwhile, *Ceratophyllum demersum* L., *Salvinia cucullata* were likely to reduce Fe, Cu, Pb and Zn in Bay Mau lake, Hanoi.

The evaluation on ability to remove Cr, Ni in water of some plant species has been done. The plant species were capable of removing Cr and Ni from contaminated water. The experiments on tolerance of 7 plant species were evaluated. Plant was washed and grown in clean water before 3 days experimental set-up. There were seven treatments sets with five replicates for each. Each plastic pot contained 6 liter water medium, with 70 gram fresh weight (FW) plant. Cr and Ni concentrations in each pot were 1, 3, 5, 7 and 10 mg / l. Preparing Cr⁶⁺, Cr³⁺ and Ni²⁺ solutions by adding K₂Cr₂O₇, CrCl₃. 6H₂O and NiSO₄.7 H₂O, respectively. After 14 days experiment, the investigated plants were harvested and then washed with tap water to remove dust, rinsed with deionized water, and kept for 10 hour to evaluate the plant fresh weight. The results showed that the tolerance of these species can be arranged in the following order: *Vetiveria zizanioides* > *Phragmites australis* > *Eichhornia crassipes* > *Pistia stratiotes* > *Ipomoea aquatica* > *Nypa fruticans* > *Enhydra fluctuans*. A treating system of Cr and Ni in contaminated water was established at pilot scale by “root zone” technology. Two plant species having high tolerance to Cr and Ni (*Vetiveria zizanioides* and *Phragmites australis*) were selected for further studies in pilot scale (0.5m³.day⁻¹). This system worked continuously in 23 weeks (Inlet wastewater is a mixture of electroplating wastewater contained Cr and Ni and animal husbandry wastewater). This inlet wastewater

contained average concentrations of Cr⁶⁺, Cr³⁺, Ni²⁺, COD, T-N as T-P as follows: 1.9, 3.2, 3.88, 111.4, 42 and 8 mg/l, respectively.

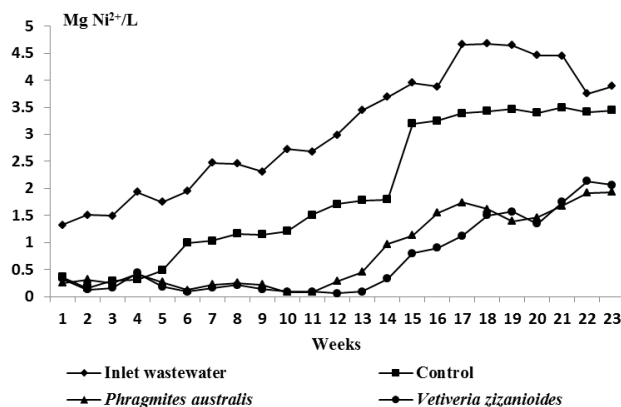


Figure 2. Ni²⁺ removing capacity of *Vetiveria zizanioides* and *Phragmites australis*

Treatment system consists of 03 cement tanks. Each tank can contain 0.5 m³ water with rock in the bottom and sand at the top. Control tank has no plant. The tanks growing *Vetiveria zizanioides* and *Phragmites australis* have plant density as 10 cm × 15 cm. Each tank has 108 plants, fresh weight of each branch is of 60 gram FW. After 23 weeks experiment at pilot scale, Ni treatment efficiencies of *Vetiveria zizanioides*, *Phragmites australis* and control reached 91.5%, 88.4% and 49.68%, respectively. Concentration of Ni²⁺ in outlet of the control, *Vetiveria zizanioides* and *Phragmites australis* were 1.95, 0.33 and 0.45 mg/l, respectively (Figure 2).

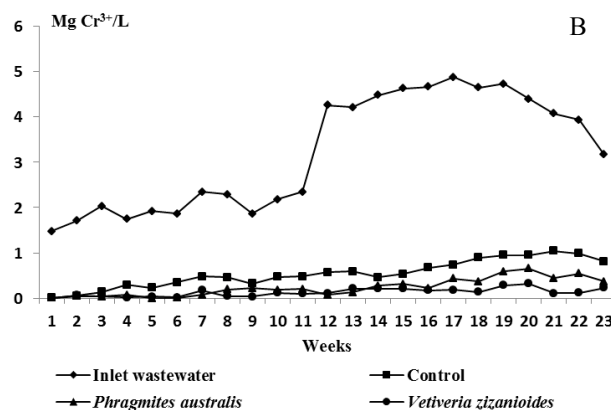
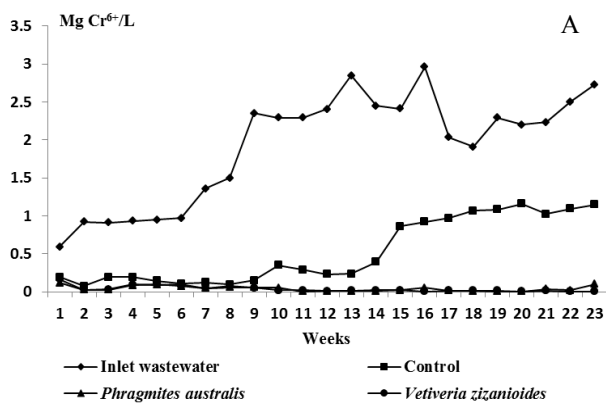


Figure 3: Cr⁶⁺ (A) and Cr³⁺ (B) removing capacity of *Vetiveria zizanioides* and *Phragmites australis*

After 23 weeks experiment at pilot scale, Cr⁶⁺ treatment efficiencies of *Phragmites australis* and *Vetiveria zizanioides* were very high reaching 97.97% and 98.12%, respectively [Fig.3]. The Cr⁶⁺ concentration in inlet wastewater of 2 treatments was 1.92 mg/L, whereas the Cr⁶⁺ concentration in outlet of *Vetiveria zizanioides* and *Phragmites australis* tank were 0.053 and 0.047 mg/L respectively. The inlet Cr³⁺ concentration of *Vetiveria zizanioides* and *Phragmites australis* tank was 3.218 mg/l, outlet of *Vetiveria zizanioides* and *Phragmites* were 0.2 and 0.24 mg/l, respectively. The treatment efficiencies by *Vetiveria zizanioides* and *Phragmites australis* were

95.91% and 92.6%, respectively. The outlet concentrations of Cr⁶⁺ and Cr³⁺ were under the limitation for industrial wastewater according to Vietnam standard (TCVN 5945-2005).

3.2. Heavy metal removal from soil by plants

3.2.1. Screening potential plants for heavy metal removal

A total of 33 different plant species samples were collected from four mining areas in Thai Nguyen

province to identify the heavy metal concentrations in their roots and shoots. The collected plant species can grow at the mine tailings or in the soils affected by mining waste. The results showed that 2 ferns, *Pteris vittata* L. and *Pityrogramma calomelanos* L. were capable of accumulating high arsenic concentrations. As concentrations in shoot and root of *Pteris vittata* L. were 5876.5 ± 99.6 and 2642.5 ± 72.3 mgkg^{-1} , respectively; while these figures of *Pityrogramma calomelanos* L. were 2426.3 ± 104.5 and 2256 ± 123.4 mgkg^{-1} . Remarkably, a large amount of As from roots of these ferns was transposed to shoot, facilitating the removal of As from contaminated soil. The Zn accumulating ability in some investigated plant species was quite high, e.g. *Equisetum ramosissimum*, *Cyperus rotundus*, and *Eleusine indica*. with Zn accumulated in shoots at 1346.2 ± 130.2 , 1201.4 ± 147.3 and 4346.8 ± 157.9 mgkg^{-1} , respectively and in roots at 3756.9 ± 145.7 , 2194.4 ± 155.7 and 3108.7 ± 213.5 mgkg^{-1} Zn, respectively. Our finding in Thai Nguyen province indicates that, two ferns *Pteris vittata* L. and *Pityrogramma calomelanos* L. are suitable for As treatment in the mining soil of Ha Thuong, Dai Tu district, four grasses *Eleusine indica*, *Cynodon dactylon*, *Cyperus rotundus* and *Equisetum ramosissimum* are the best at keeping Pb, Zn concentrations in their root. So we can use these grasses for phytostabilization of Pb and Zn in Tan Long, Dong Hy district.

Based on the screening results, we carried out some experiment concerning with the potential plants as good candidates for phytoremediation of heavy metal polluted soil.

3.2.2. *Brassica juncea*

As, Pb and Cd accumulations of *Brassica juncea* were quite good. All 3 heavy metals (Cd, As and Pb) can be accumulated in roots more than in the shoots. In trace concentration, the heavy metals can stimulate plant growth but with higher concentrations (Cd > 25 ppm, As > 200 ppm and Pb from 2000 to 3000 ppm) they inhibited the plant from growing. When Pb concentration in soil was 3000 ppm, the Pb accumulation in shoots and roots were 202.9 and 2425.9 ppm, respectively. While As and Cd concentrations in the soil was 25 ppm, the content in shoots and roots were 185.6 and 228.9 ppm (for As); 185.6 and 228.9 ppm (for Cd), respectively. *Brassica juncea* can be used to remove As, Pb and Cd concentration in contaminated soil but it should be noted that this plant also a popular green vegetable for people.

3.2.3. *Vetiveria zizanioides*

In soil contaminated with Pb from 1400.5 to 2530.1 mg / kg, *Vetiveria zizanioides* still grew well after 90-day treatment. Some characteristics of plant growing on Pb contaminated soil such as height, root length, biomass and the Chlorophyll concentration increased more than those on control soil (soil without Pb). Pb concentration analysis in soil after this experiment showed that, the Pb extraction effect from the contaminated soil by *Vetiveria zizanioides* could reach from 87% to 92.6%. However, the average Pb accumulation in its shoots and roots were not

high being only 24 and 349 ppm, respectively. This species also can accumulate As and Cd taken from soil. Many our further experiment results showed that feasibility of using *Vetiveria zizanioides* as phytostabilization agent for Pb, Cd and As in contaminated soils.

3.2.4. *Eleusine indica*

Eleusine indica can be used for remediating the soil contaminated with Pb and Zn. Results of the survey showed that this plant can grow in the waste area of lead, zinc processing factory. Analyzing Pb and Zn concentration in soil and plants showed that if soil contained 4316.96 ppm Pb, there would have 664.45 and 4638.17 ppm Pb in shoots and roots of the plant, respectively; if soil contained 1000 ppm Zn, there would have 761.6 and 2011.3 ppm in shoots and roots, respectively. *Eleusine indica* could grow well at the concentration of Pb and Zn in soil lower than 5000 and 1000 ppm, respectively.

3.2.5. *Pennisetum purpureum*

When Pb concentration in the soil was 3600 ppm, Pb accumulated levels in shoot and root of the plant were 164.3 and 1009.1 ppm, respectively. When Cd concentration in soil was 31.5 ppm, the Cd accumulated concentrations in shoot and root of the species were 5.7 and 320.1, respectively. Some other result showed that, the grass accumulated Pb and Cd mainly in roots and the plant grown in the soil with higher heavy metal concentration could accumulate them higher in their biomass.

3.2.6. *Pteris vittata* and *Pityrogramma calomelanos*

Two ferns *Pteris vittata* and *Pityrogramma calomelanos* can grow in the mining soil containing 15,146 ppm As. Although they are As hyperaccumulators, the plants still have ability to accumulate Cd, Pb and Zn. *Pteris vittata* and *Pityrogramma calomelanos* can tolerate 5000 and 4000 ppm Pb; 1200 and 300 ppm Cd, respectively. The highest level of As accumulation in *Pteris vittata* and *Pityrogramma calomelanos* are 6042 and 4034 ppm (in the fronds); 3756 and 2256 (in the roots), respectively. From 3 to 4 months after growing there is appropriate time for harvesting biomass plants if applied in practical processing.

4. Conclusion

Base on the evaluating Cr and Ni tolerance of seven potential plant species, two plant species having a highest tolerance to Cr and Ni concentrations are *Vetiveria zizanioides* and *Phragmites australis*.

Screening research of 33 plant species in Thai Nguyen province indicated that two ferns *Pteris vittata* and *Pityrogramma calomelanos* were suitable for As treatment in the mining soil of Ha Thuong, Dai Tu district. Four grasses like *Eleusine indica*, *Cynodon*

dactylon, *Cyperus rotundus* and *Equisetum ramosissimum* were the best in accumulating Pb, Zn in their roots.

Other investigated plant species like *Brassica juncea*, *Pennisetum purpureum*, *Vetiveria zizanioides* were potential to remediate the soil contaminated with As, Cd, Pb and Zn.

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6. References

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