Phytoremediation of Heavy Metals in Mine Drainage by Tropical Aquatic Plants

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Abstract: Acid mine drainage (AMD) is a major environmental problem associated with mining activities. There are several methods to remediate these mine drainage by neutralizing and removing metals from solutions. Those mechanisms can be mainly divided into active or passive systems, which this study describes the utilization of aquatic plants abundant in tropical conditions, in line with the passive remediation technique known as phytoremediation. The plants were selected based on the survivability in the tropical conditions and efficiency of extracting metals. *Eichhorniacrassipes*(Water Hyacinth) was the most survivable plant, and was deployed to absorb Fe, Cu and Cd from solutions reflecting the generic characteristics of mine drainage. The drainage solutions were created, with increasing concentrations of each ion starting from the permissible threshold values in accordance to the World Health Organization (WHO) guidelines. The results reflect that the efficiency of phytoremediation process with Water Hyacinth was optimum when the solutions were neutral (pH ~ 7) and deteriorating under acidic conditions (i.e. pH<7).

Key words: Phytoremediation, Mine drainage, *Eichhorniacrassipes*

1. Introduction

Mining industry produces wastewaters most often encountered at waters draining from active and abandoned mines and mine waste sites. The sulphur rich environments results acidic waters containing elevated concentrations of heavy metals, causing a threat to the environment. The exposure of sulphidic minerals such as pyrites to both oxygen and water leading to rapid oxidation, is the main cause of forming acidic mine drainage (Lottermoser, 2010). Thus wherever there is a mineral deposit containing traces of sulphide's, there exists a significant potential of witnessing acid mine drainage conditions. The adverse effects of these conditions encounter not only during the cause of mining but also even after the mine has been abandoned.

Even though the environmental impacts of mining industry cannot be coherently assessed, the estimations suggest that ~19,300 km of streams and rivers, and ~72,000 ha of lakes and reservoirs worldwide had been seriously damaged by mine effluents by latter stages of the twentieth century (Johnson and Hallberg, 2005). With the industry norms inclined to maximize the profit through increased production, providing cost effective and environmental friendly engineering solutions has become limited in practice (Dudka and Adriano, 1997).

Extraction of earth resources is continuous in Sri Lanka, without much contrast to the rest of the world. The ever increasing population and expanding infrastructural developments in context to the limited availability of land, the mine sites located in residential neighbourhoods has become unavoidable. Hence, systematically addressing the potential issue such as effluent discharges that could rise as a result of mining activates is a must. Accordingly, surface water bodies and underground water resources are of prime concern where contamination should be minimized. Phytoremediation is an environmental friendly passive system that could regulate and absorb the contaminants, where studies within the local context are limited.

2. Materials and methods

2.1 Plant selection for the phytoremediation

Suitable plant species were selected based on the availability, sustainability under tropical conditions and ability to hyper-accumulate heavy metals of interest.

Among the available *Azollapinnata*(Water Velvet), *Eichhorniacrassipes* (Water Hyacinth) and *Pistiastratiotes* (water Cabbage) were the main plants that had the capability of absorbing a variety of metals. When tested for survivability under the laboratory induced mine drainage conditions only Water Cabbage and Water Hyacinth (Figure 1) were successful. Water Hyacinth was selected for the remediation process due to the range of metals (Cu, As, Ag, Al, Se, Co, Hg, fe, Pb, Cr, Zn, Cd, Ni, U) that it could absorb with comparison to water cabbage which can absorb only (Cr, Cd, Pb, Cu, Hg, Al, Zn, Co, Fe, Mn).

Water Hyacinth plants (i.e. ~2 to 4 months of age) were identified and a pool was created. Plants with healthy dark green appearance were selected from the pool. The leaves were measured and checked for appearance and roots were also examined to confirm that they are lush in appearance with dark purplish roots. The lengths of the roots were measured (~15 cm in length) together with the weight of each plant.

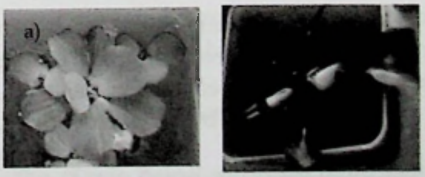

Figure 1: *Pistiastratiotes (a) and Eichhorniacrassipe (b)*

2.2 Sample preparation and testing

Laboratory samples (27 in total) were prepared to mimic the mine drainage conditions with variable concentrations of specific pollutants. The maximum pollutant concentrations reported on mine drainage by Wildeman*et al*, (1993) and the WHO drinking water quality standards were considered when creating laboratory samples with varying concentrations of Fe, Cu and Cd. The optimum pH level of the solutions to efficiently absorb the contaminants and plant sustainability was also assessed prior to performing the tests for phytoremediation. High acidic and Fe rich environments were not conducive with regard to the selected plant species. Sample calculations of the masses, are given in Table 1.

Bolgoda Lake's water was used to create the drainage samples, as the nutrients required for the growth of the plants were present in the lake water. Initially, the lake water was tested for the presence of Cd^{2+}, Cu^{2+} and Fe^{2+} ions and discovered that all the values were negligible. SOLAAR Atomic Absorption Spectrometer and UV visible Spectrophotometer (HACH DR 2800) was used for this purpose.

The sample containers were 3.5 *l* in volume. They were having increasing concentrations of each element (Cd^{2+}, Cu^{2+} and Fe^{2+}) by a factor of 2, starting from the maximum permissible level indicated by the WHO.

The testing for the phytoremediation of the three heavy metals was carried out, until the plants were dead or the concentration values of the contaminants would have reached to zero. Initially on the Fe^{2+} containers a significant sedimentation of the red-brownish material (precipitation of $Fe(OH)_3$) was observed. After the first few days the precipitation remained constant.

Table 1.Preparation of Fe, Cu and Cd concentrations

Required Fe^{2+} concentrations (mg/l)	Required Fe mass (mg) to be added to the 3.5 L containers	$FeSO_4.7H_2O$ mass (mg) to be added
0.3	1.05	5.230
0.6	2.1	10.46
1.2	4.2	20.918
Required Cu^{2+} concentrations (mg/l)	Required Cu mass (mg) to be added to the 3.5 L containers	$CuSO_4.5H_2O$ mass (mg) to be added
1	3.5	13.752
2	7	27.503
4	14	55.006
Required Cd^{2+} concentrations (mg/l)	Required Cd mass (mg) to be added to the 3.5 L containers	volume of 1000 ppm standard solution (µl)
0.005	0.0175	17.5
0.01	0.035	35
0.02	0.07	70

15 *ml* samples were taken from each drainage container, adhering to appropriate sampling techniques and using the pipette. The quantitative analysis was done using the SOLAAR Atomic Absorption Spectrometer and UV visible Spectrophotometer. Additionally, the changes in appearance (colour, size, any signs of infections, etc.) of the shoots and leaves were observed throughout the test and recorded.

3.Results

The absorbance of Fe^{2+}, Cu^{2+} and Cd^{2+} samples recorded for the Water Hyacinth plants are indicated in figures 2, 3 and 4 respectively.

During the first two days of the study, a slight ambiguity in the absorbance values were indicated in Cu^{2+} concentrations but after that the absorbance was quite linear and consistent. The results obtained for Cu^{2+} concentrations show a similarity to the studies of Lu *et al*, (2004) and Mokhtar*et al*, (2011).

Consistent absorbance was evident in Cu^{2+} and Cd^{2+} concentrations. Cd^{2+} concentrations were totally absorbed by the plants, whereas prior to the full accumulation the plants in Cu^{2+} concentrations died. A ragged inconsistency is displayed in the curve for the Fe^{2+} absorbance, by the plants.

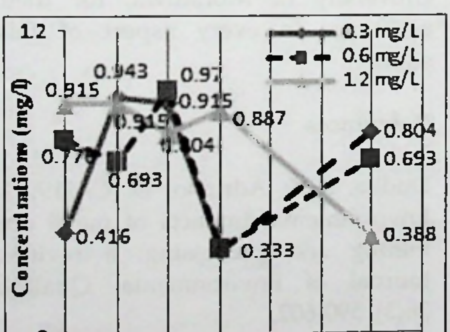

Figure 2: Absorption of Fe^{2+} concentrations by Water Hyacinth

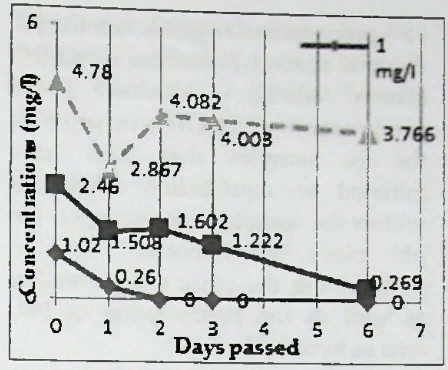

Figure 3: Absorption of Cu^{2+} concentrations by Water Hyacinth

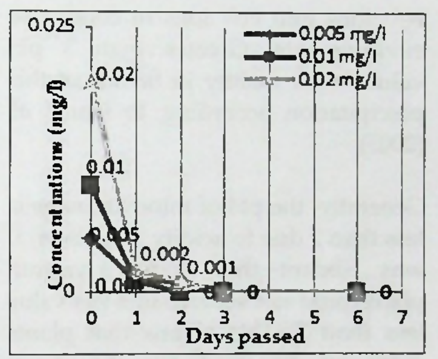

Figure 4: Absorption of Cd^{2+} concentrations by Water Hyacinth

6. Discussion

Water Hyacinth plant demonstrated a considerable acclimatization to the laboratory environment, compared to the other plants. Hence, it may have been able to perform the accumulation process efficiently.

The plants being saturated with Fe^{2+} ions in the cellular level probably have caused the ambiguous absorption of Fe^{2+}, in figure 3. If the plants were hydroponically cultivated this would have been minimized and more coherent results could have been obtained.

Fe^{3+} precipitation begins when the pH value is around 7, forming a reddish brown sludge. However, the precipitation of $Fe(OH)_3$ in some of the Fe samples may also have initiated an equilibrium conditions within the samples. Accordingly, the pH plays an important role in determining the plant's survivability as well as the precipitation of Fe^{3+} ions as hydroxides.

The $Fe(OH)_3$ precipitation may have encountered, due to the oxidization of Fe^{2+} ions into Fe^{3+} ions in conducive environments. Greater than 3 pH values were mainly in favour of this precipitation according to Gan*et al*, (2005).

Generally, the pH of mine drainage is less than 7 due to acidity. However, it was evident that Water Hyacinth plant could not survive in a pH value less than 7. This means that plants may not be used for the direct treatment of acid mine drainage. Instead, they can be employed once the pH value has been regulated. The effects of pH variations should be extensively studied to encompass a comprehensive knowledge.

Once Water Hyacinths or any other plants were used for a remediation process, the disposal of aerial tissues (i.e. stems and leaves) can become a concern. Hence, investigation on appropriate plant disposal methods with respect to the phytoremediation of heavy minerals also needs to be comprehensively addressed.

5. Conclusions

Phytoremediation of Fe, Cd and Cu using Water Hyacinth plant under laboratory conditions was a success. There exists a significant potential for the application of the plant, in mine drainage, to perform heavy metal absorption in local environments under appropriate conditions; if the Water Hyacinth plant could be utilized in natural wetlands, the phytoremediation capability of the plant would be significant in counteracting the accumulation of Heavy Metals. The Water Hyacinth plant may be deployed as a treatment unit within a mine drainage treating process in particular, by means of floating wetlands.

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