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PHYTOREMEDIAL POTENTIALS OF *Ipomoea aquatica* AND *Colocasia esculenta* IN SOILS CONTAMINATED WITH HEAVY METALS THROUGH AUTOMOBILE PAINTING, REPAIRING AND SERVICE CENTRES

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Abstract

Heavy metal pollution is one of the biggest environmental issues at present. The study was conducted with the objectives of evaluation of soil contamination of heavy metals with Cu, Zn, Pb, Mn, Cr and Fe by automobile repairing, painting and service centres in Kandy area, Sri Lanka, and the phytoremediation potential of using *Ipomoea aquatica* and *Colocasia esculenta* in such soils. Soil and plant samples from ten sites associated with these industries were analyzed for the Cu, Zn, Pb, Mn, Cr and Fe concentrations and Bioconcentration (BCF) and the translocation factors (TF) were determined.

The soils associated with these nutrients were highly contaminated with all the heavy metals studied and both plant species accumulated these heavy metals in different concentrations. The automobile repairing centres caused highest pollution by Cu, Mn and Cr, automobile painting centres caused highest pollution by Pb and Zn, and automobile service stations caused highest pollution by Cr and Fe. Fe concentration was the highest in contaminated soils. Heavy metals were accumulated in all plant parts, roots containing the highest concentrations. Considering the TF and BCF, *I. aquatica* was identified to be suitable for phytoextraction of Cu and Mn, while *C. esculenta* was found to be suitable for phytostabilization of Cu, Pb, Mn, Fe and Zn. Uncontrolled release of waste containing heavy metal pollutants, and consequences of *I. aquatica* and *C. esculenta* growing in such contaminated sites may cause heavy health hazards.

Key words: Cu, Zn, Pb, Mn, Cr, Fe, contamination, hyperaccumulation, phytoremediation

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1. Introduction

Heavy metals are amongst the most toxic contaminants in the environment. They are defined as elements with metallic properties and an atomic number more than 20 (Tangahu *et al*., 2011). Anthropogenic activities such as industries, energy production, constructions, vehicle exhaust, waste disposal, as well as coal and fuel combustion cause production of heavy metals (Li *et al*., 2001; Bai *et al*., 2008). Dispersion of these heavy metals to non contaminated areas occurs in many different ways, while contributing towards contamination of the ecosystem (Gaur and Adholeya, 2004). A large number of sites worldwide have already been contaminated with high concentrations of heavy metals, making these sites unsuitable for any potential use. This problem is more severe in developing countries such as Sri Lanka, where strict monitoring mechanisms on the waste disposal to the environment from industries do not exist. Therefore, it is an urgent matter to find effective and affordable remediation technologies to clean the contaminated environment.

Heavy metals usually do not undergo biodegradation, instead accumulate in living organisms causing bioaccumulation followed by health issues (Pehlivan *et al.,* 2009). Their soil residence may have negative effects on plant growth, ground cover and soil microflora (Roy *et al*., 2005). Therefore, heavy metals should be removed physically or be transformed into nontoxic compounds.

Though several methods have been used to clean up the environment, most of them are costly and do not yield optimum results. Remediation of heavy metal contaminated soil involves chemical and thermal methods or excavation and subsequent disposal to landfill sites. However, most of these technologies are expensive, technically complex and difficult to apply (Rukhshaee *et al*., 2009); hence their implementation in countries such as Sri Lanka is not feasible. In this context, phytoremediation can be considered as an effective and affordable solution to remove heavy metals from contaminated soils.

Phytoremediation is the technology that uses selected plants to clean up contaminants from soils, sediments and water (Tangahu *et al*., 2011). This technology uses exceptional metal accumulating capacity of some plants, which are known as 'hyperaccumulators' that tolerate high concentrations of heavy metals in their systems (Chaney, 1983; Baker *et al*., 2000). These hyperaccumulators have extremely high capacity to uptake metals, together with the translocation, bioaccumulation and constant degradation abilities (Hinchman *et al*., 1998). Plant species that are able to survive in contaminated soils rich in Zinc (Zn), Copper (Cu), Lead (Pb), Cadmium (Cd), Nickel (Ni), Chromium (Cr), and Arsenic (As) are divided into two main groups; pseudometallophytes that grow on both contaminated and non-contaminated soils and the absolute metallophytes that grow only on metal-contaminated and naturally metal-rich soils (Baker, 1987).

Many plant species have been identified of having hyperaccumulation properties. *Ipomoea reptans* (Water spinach), *Eichhornia crassipes* (water hyacinth), *Salvinia molesta, Ipomoea aquatica*

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(Kankun) and *Colocasia esculenta* (Habarala) are some examples that have the potential of hyperaccumulation of heavy metals. Some of these species are found to be quite effective in remediating contaminated areas (Reeves and Baker, 2000; Mahamud *et al*., 2008; Bindu *et al*., 2010; Kruatrachue *et al*., 2015; Mazumdar and Das, 2015). Results of many studies have proven that *I. aquatica and C. esculenta* have the potential to remediate contaminated soil, water and sediments. *C. esculenta* is also a promising plant species for remediation of waste water polluted with Pb and Cd (Bindu *et al*., 2010).

There are many large and small scale industries in Sri Lanka where the wastes containing high amounts of heavy metals are directly released to the environment. Some of the above mentioned hyper accumulators grow in such environments naturally; hence, they can be used effectively for phytoremediation.

Present study was executed with the objective of assessing the heavy metal accumulation of soils in land areas near automobile painting, servicing and repairing centres in the Kandy area of Sri Lanka, and to evaluate the phytoremediation potential of *I. aquatica* and *C. esculenta* of such soils.

2. Material and Methods

This study was carried out from July to September 2011 at the Department of Crop Science, Faculty of Agriculture, and Department of Geology, Faculty of Science, University of Peradeniya. Sampling was done in the Kandy area of Sri Lanka, located at 7.2955°N and 80.6356°E at an average elevation of 506 m. Locations of three common small-scale industries, i.e. automobile painting, automobile repairing and automobile service centres were selected for the study, since there is no monitoring mechanism of the release of waste to the environment from these industries. All these locations were within or in close proximity to the Kandy municipal area and located in lowlands which were prone to water logging during the rainy season. Ten of such sites, including four automobile repairing, three automobile painting and three automobile service centres were selected for the study.

I. aquatica and *C. esculenta* were found to be commonly growing in all the above sites. Soil and plant samples of *I. aquatica* and *C. esculenta* were collected from lower elevation of these sites, where stored water flows in. Samples were collected in four replicates from each site. Soil and plant samples were also collected from upper elevations of the industries where no contamination from industries was evident due to stored water runoff and these were considered as controls. The plant samples were oven dried at 73^0C to a constant weight. Dry weight was taken using an analytical balance. Dried plant samples were ground using a grinder and sieved through using 1mm mesh sieve. The soil was air dried to a constant weight, ground using a mortar and a pestle, and sieved using a 1mm mesh sieve.

Soil and plant samples (500mg each) were digested using 67% HNO_3 at 150^0C for 8 hours (Hseu, 2004) in a furnace (Thermolyne 62700). The samples were read against standard solutions of Pb, Fe, Cr, Mn, Zn, and Cu using an atomic

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absorption spectrophotometer (Avrian AA240FS).

The ability to translocate metals from roots to above ground parts of the plants were evaluated by means of the bioconcentration factor (BCF), which is defined as the ratio of metal concentration in the roots to that in soil ([metal] root/ [metal] soil). The translocation factor (TF) was calculated as the ratio of metal concentration in the shoots to that in roots ([Metal] shoot/ [Metal] root) (Stephen *et al*., 2013).

Data were analyzed using Analysis of Variance and the mean separation was done using Duncan's multiple range test, using SAS statistical package.

3. Results

The mean concentrations of different heavy metals in the soil and plant samples collected from the three different types of industrial sites are given in Table 1, and their concentration as a percentage of the concentration in the control sites are given in Table 2.

Table1. The concentration of different heavy metals in plant and soil samples from different experimental sites and control sites.

Site	Sample Type	Concentration of Heavy Metals (mg/kg)					
		Cu	Pb	Mn	Cr	Fe	Zn
Automobile repairing	Soil	87	7.85	500	82	45848	110
	I. aquatica	206	2.38	760	49	22234	69
	C. esculenta	243	8.65	692	58	8216	87
Automobile painting	Soil	59	10.92	384	62	26198	118
	I. aquatica	83	5.67	488	41	21669	192
	C. esculenta	89	7.08	275	44	7337	187
Automobile service	Soil	109	6.33	577	81	27024	108
	I. aquatica	102	4.67	325	57	17574	71
	C. esculenta	104	6	328	53	45014	43
Control	Soil	11	0	23	23	293	82
	I. aquatica	17	0	23	18	239	337
	C. esculenta	69	0	25	23	316	441

Results showed that soils and plants of each site contained high concentrations of the heavy metals studied (Cu, Pb, Mn, Cr and Fe) compared to the control (Table 1). The mean accumulation of Cu, Pb, Mn, Cr, Fe in soil were 672%, 837%, 2015%, 228% and 11180% respectively compared to the control, irrespective of the industry. When taken as an average in each industry, the highest contaminations of Cu, Mn and Cr were from the automobile repairing centres compared

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to the other two industries. Automobile painting centres mostly caused pollution by Pb, whilst pollution by Cr and Fe was mostly by the automobile service stations compared to the other industries considered. Of all the heavy metals considered, the highest concentrations were with Fe, followed by Mn (Table 2). The only heavy metal that did not show a difference with the industries and control was Zn; The Zn accumulation in different plant species and industries did not show any trend. All other heavy metal concentrations in plants were higher than in the control. However, the differences in the concentrations of heavy metals between different industries were not statistically significant.

Table 2. The concentration of heavy metals in plants and soil samples in experimental sites as a percentage of their concentration compared to control sites.

Industrial site		Concentration of Heavy Metals (%)					
		Cu	Pb	Mn	Cr	Fe	Zn
Automobile repairing	Soil	691	785	2073	259	15561	34
	I. aquatica	1148	238	3133	171	9203	-80
	C. esculenta	253	865	2693	155	2503	-80
Automobile painting	Soil	436	1092	1567	170	8849	44
	I. aquatica	405	567	1975	128	8966	-43
	C. esculenta	29	708	1009	93	2225	-58
Automobile service	Soil	889	633	2405	255	9131	32
	I. aquatica	516	467	1280	214	7253	-79
	C. esculenta	51	600	1224	132	14167	-90

The concentrations of the individual heavy metals in different parts of the two species of plants considered, are shown in figures 1 a to f.

Fe was accumulated in largest quantities in both species, under the present conditions, followed by Mn and Cu. Lowest concentrations were with Pb. In both species, roots accumulated more heavy metals followed by stems. In general, concentrations of the heavy metals in leaves were lower than in roots and stems. Cr, Fe and Zn concentrations in leaves of both species were very low despite high concentrations in stems and roots. Further, in the leaves concentrations of Cr, Fe and Zn were less than the concentrations of Cu, Pb and Mn, comparable to that of the roots and stems.

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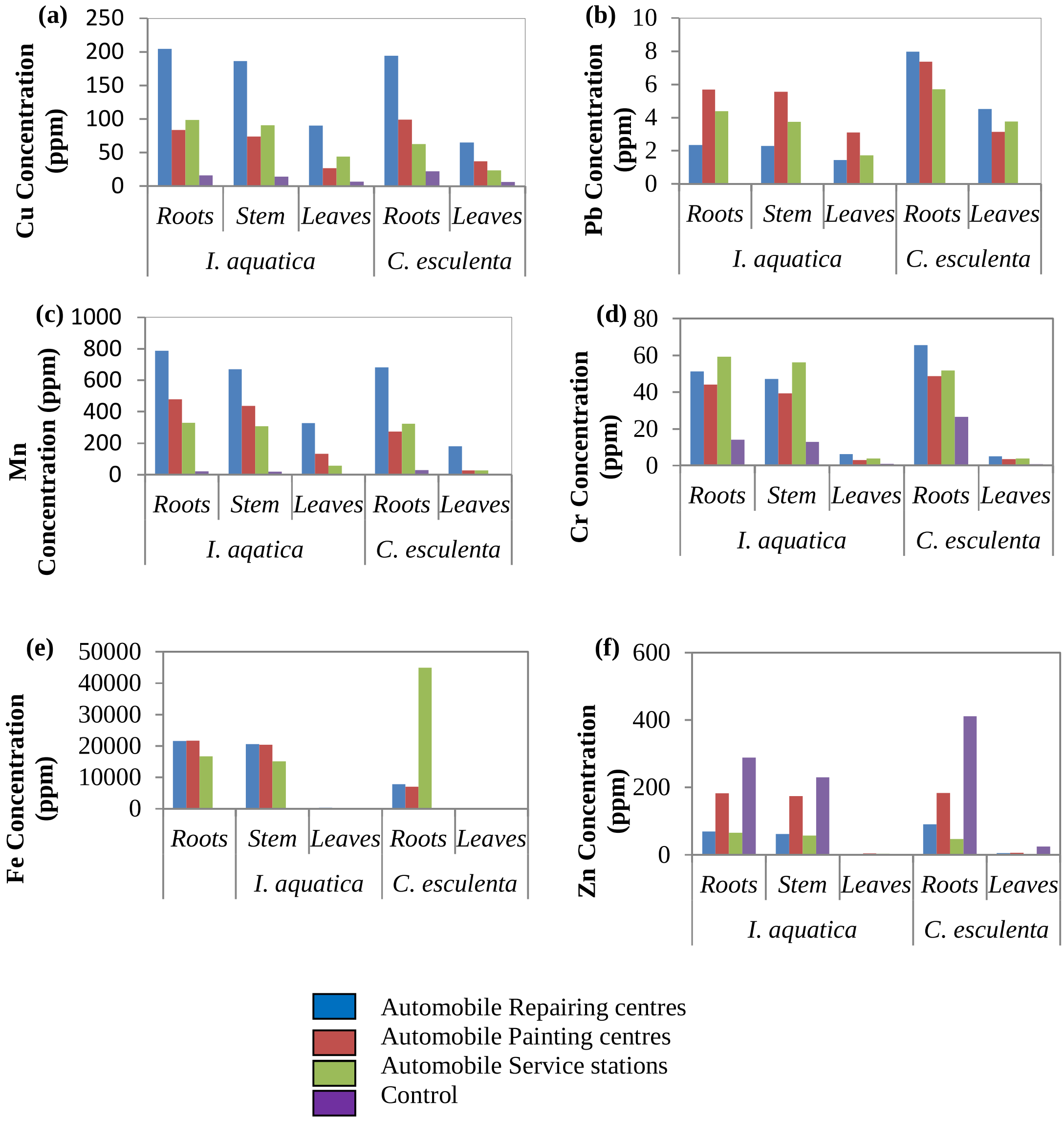

Figure 1. The concentrations of heavy metals in different parts of *I. aquatica* and *C. esculenta* plant species (a) Cu, (b) Pb, (c) Mn, (d) Cr, (e) Fe and (f) Zn

4. Discussion

4.1 *Heavy metals in the soil and plants*

All the three industries caused pollution of the soil by heavy metals. Heavy metals such as Pb are known to be present in fuel, which is used in its purification (Harrison and Laxen, 1981; Culbard *et al*., 1988; Ho and Tai, 1988). It is also contained in paints. Hence, a most probable source of such contamination of Pb may be waste gasoline. Scraping of the old paint, removal of used oils, washing of

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different automobile parts and *ad-hoc* releasing them to the environment may have caused these contaminations in the soil. The accumulation of some of these heavy metals was quite alarming, such as Fe and Mn, since they were present in extremely high concentrations compared to the control. These metals are very commonly used in various alloys in automotive industries and spare parts, and could contaminate the soil upon their cleaning and rusting. Contamination of water bodies by these heavy metals may be possible, which may lead to more severe long lasting problems. The statistical non-significance of the differences in heavy metals between different industries may be due to the variation between the different locations.

According to the percentages given in table 2, it is very clear that all three industrial sites have high concentrations of heavy metals compared to the control, indicating that industries have released their waste directly to the environment. The highest percentage was recorded for Fe, followed by Mn and Cu. When heavy metals present in the soil, they were taken up by both plant species studied, and accumulated, as shown in Tables 1 and 2. This was true for all the heavy metals studied, as the concentrations were highest than in the control, indicating bioaccumulation (Table 1). In many situations, the plants contained higher concentrations of heavy metals than the soil in the same locations. Both plant species appeared to be healthy under high concentration of heavy metals without showing any toxicity symptoms.

Though both plant species were exposed to same metal concentrations, their capabilities of accumulation varied with the metal. When the average value of the concentration of each heavy metal of the three locations was considered, the concentrations of Cu, Pb and Cr were higher in *C. esculenta* (145, 7, 52 mg/kg respectively) than in *I. aquatica* (130, 4, 49 mg/kg respectively), and the Mn, Fe and Zn concentrations were greater in *I. aquatica* (524, 20492, 110mg/kg respectively) than in *C. esculenta* (432, 20189, 105 mg/kg respectively), irrespective of the industry. In *I. aquatica,* Mn, Fe, Cu, Zn, Pb and Cr concentrations were in the range of 325-760 ppm,17574-22234 ppm 83-206 ppm, 69-192 ppm, 2.38-4.67 ppm and 41.00-56.50 ppm respectively and in *C. esculenta* they were in the range of 275-692 ppm, 7336-45014ppm, 89-243 ppm and 47-187ppm, 6.00-8.65 ppm and 43.92-58.00 ppm respectively. The Cu concentrations were larger than in the soil in both these species, and the Mn concentration was larger in *I. aquatica* than in the soil.

The ratio of different heavy metals in the roots of the two species considered was close to 1, indicating similar capacities of accumulation of the heavy metals by both species. However, there were two exceptions, i.e., near the automobile repairing industry where Pb accumulation was approximately 3.6 times greater in C. *esculenta* than in *I. aquatica,* and near the automobile repairing and painting industries Fe accumulation was about 2.7-2.9 times higher in C. *esculenta* than in *I. aquatica*.

4.2 *Heavy metal accumulation and translocation*

Results showed that after uptake of heavy metals from the contaminated soil into the

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roots of the plants, they were translocated to different plant parts in lower concentrations. The fact that all heavy metal concentrations in leaves were significantly lower than the concentrations in roots and stems suggested that the metals were bound to the root cells and their translocation to the leaves was limited. These results confirm some other earlier studies (Bindu *et al*., 2010). The higher concentrations of these heavy metals also suggest that these two species can be used in phytoremediation of the above metals. These have been suggested as potential phytoremediators of heavy metals such as Fe, Mn, Cr, Zn, Pb, Cu, Ni, and Cd in some other studies too (Reeves and Baker, 2000; Mahamud *et al.*, 2008; Bindu *et al*., 2010; Kruatrachue *et al.,* 2015; Mazumdar and Das, 2015).

The BCF and TF values were calculated to be used to evaluate the ability of plants to accumulate heavy metals (BCF) and to translocate (TF) (Table 3). These values are useful in determining whether these species could be used for phytoextraction and phytostabilization purposes as per Yoon *et al*. (2006).

Table 3. Bioconcentration (BCF) and translocation factors (TF) calculated for different heavy metals for *I. aquatica* and C. *esculenta* grown in heavy metal contaminated soil.

Plant species		Cu	Pb	Mn	Cr	Fe	Zn
I. aquatica	BCF	2.4	0.3	1.6	0.7	0.6	1.6
	TF	1.4	1.6	1.3	1.0	0.9	0.3
C. esculenta	BCF	1.4	1.0	0.6	0.8	1.7	1.6
	TF	0.3	0.6	1.4	0.1	0.01	0.1

Plants with both BCF and TF values greater than one have the potential to be used in phytoextraction. In addition, plants with BCF greater than one and TF less than one have the potential to be used for phytostabilization (Yoon *et al*., 2006). Phytoremediation technologies involve several mechanisms of phytoextraction, phytostabilization, rhizofiltration and phytovolatilization (Anon., 2009). Phytoextraction is the uptake of contaminants by plant roots and translocating them to shoots that can be harvested and burned gaining energy and recycling the metals from ash. Phytostabilization is defined as immobilization of contaminants in the soil and groundwater through absorption and accumulation, adsorption onto roots or precipitation within the root zone preventing their migration in soil (Ibeanusi, 2004; Erdei *et al*., 2005; Erakhrumen and Agbontalor, 2007). Therefore, ability of plants to accumulate metals from soils can be estimated using BCF, and their ability to translocate metals from roots to shoots can be measured using TF (Deng *et al*., 2004; Yoon *et al*., 2006).

In the present study, values of both BCF and TF were greater than 1 were recorded in *I. aquatica,* for Cu and Mn (Table 3). When the BCF values were

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greater than 1, the TF values were less than 1 in *C. esculenta* for Cu, Pb, Fe and Zn. Therefore, it can be inferred that amongst the tested plant species, *I. aquatica* was suitable for phytoextraction of Cu and Mn, while *C. esculenta* is suitable for phytostabilization of Cu, Pb, Mn, Fe and Zn.

I. aquatica and *C. esculenta* were used in this study, since these were the only common species to the sites examined. There were many other species growing in these sites which were not common in both sites. These plants also did not show any apparent toxicity symptoms despite quite high concentrations of heavy metals. Testing such species for their phytoremediation potential will also be very useful.

However, *I. aquatica* and *C. esculenta* should be used for phytoremediation purposes with caution, since both are edible species. *I. aquatica is* a commercially cultivated popular green vegetable in Sri Lanka, which has a high domestic demand as well as a demand from hotels and restaurants. *C. esculenta* is also consumed as a root vegetable in rural areas. Consumption of these plant species growing in polluted soils could have direct impacts on health of local people. Green vegetables such as *I. aquatica* growing wild in abandoned lands are collected by vendors due to the high prices during certain periods. Therefore, strict measures should be adopted against using these species growing in contaminated soils for human consumption. The study also emphasizes the importance of implementation of regulatory measures against environmental pollution as the uncontrolled release of pollutants to the environment by various small scale industries cause accumulation of heavy metals in soil and plants, and may cause irreversible damage to the environment including the soil, its fauna, flora and humans.

5. Conclusion

This study revealed that automobile repairing, painting and service centres cause high pollution of soils in Kandy, due to heavy metal contamination. The heavy metals such as Cu, Pb, Mn, Cr, Fe and Zn were present in such contaminated soils. It was also revealed that two edible plants, *I. aquatica* and *C. esculenta* absorb these heavy metals and accumulate them. Concentration of all the above mentioned heavy metals were higher in roots than in shoots indicating that these metals were bound to the root cells and their translocation to the leaves was limited. It was also found out that *I. Aquatica* is suitable for phytoextraction of Cu and Mn, while *C. esculenta* is suitable for phytostabilization of Cu, Pb, Fe and Zn. People should be cautioned about using these species growing in contaminated soils as a food, since they can contain high levels of heavy metals.

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