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ON

PHYTOREMEDIATION POTENTIAL FOR REMOVAL OF HEAVY METALS FROM CONTAMINATED SOILS

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ABSTRACT

The Industrial revolution led to serious environmental pollution such as heavy metals and other hazardous waste pollutants in the soil. Heavy metal pollution has become one of the most serious environmental problems. The impact of heavy metals on soil, plants, aquatic environment and human health can lead to serious diseases and even death. Phytoremediation is the method that can be used as an alternative solution to the heavy metal treatment process. Phytoremediation technique is based on the uses of plants having the properties to accumulate heavy metals in heavy metal contaminated areas. Choosing suitable plant species becomes an important factor of phytoremediation that makes the healing process effective. Uses of plants having such properties combined with high biomass may be more efficient for this purpose. From the findings *Pinus eldarica, Wistaria sinensis, Morus alba, Brassica juncea, Pteris vittata, and Nigral morus* species were found effective in accumulation of different heavy metals.

Keyword: Phytoremediation, heavy metals, metal concentration species.

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CHAPTER I
INTRODUCTION

With the industrial revolution, life has become much easier, but every facility comes at a cost, in this case an increase of global pollution. Various industries have introduced a variety of pollutants into the environment, releasing their wastes into water bodies and landfills without any treatment. Various pollutants can lead to environmental imbalance and affect the organisms and their ecology. Heavy metals are among the pollutants that cause the most serious and deadly consequences for all living things. They may proceed with water to obtain agriculture or other land in use. Once within the soil, they will either leach down to the water level or stay in soil. This is where they enter the food chain, which affects all life forms and disturbs ecosystems.

Generally, heavy metals are mentioned as elements having a density quite 5g cm^{-3}, and most transition elements, metalloids, actinides and lanthanides (Clemens *et al.,* 2002). In biological processes, heavy metals are two types: essential heavy metals and nonessential heavy metals. Essential heavy metals are needed by the organisms during a really low quantity and include iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), nickel (Ni), cobalt (Co) and molybdenum (Mo). Contrastingly nonessential heavy metals aren't wanted by organisms for its survival like cadmium (Cd), lead (Pb), arsenic (As), mercury (Hg), and chromium (Cr) (Ali *et al.,* 2013). Because heavy metals are non-biodegradable, the increase in their concentrations can be potentially toxic to the life on earth. Humans, plants, and animals are all equally ruined by enhanced levels of heavy metals. Even the microorganisms within the soils are threatened in presence of their poisonousity because heavy metals hinder their biological schemes by involving in their cells and tissues. Therefore, they will introduce poisonousity by making reactive oxygen species, which may guide to cell damage like macromolecule degradation, ion uptake and DNA damages. In plants, heavy metals especially can affect the method of photosynthesis by interfering with electron transport chain water relations, and biochemical and enzymatic activities (Qadir *et al.,* 2014).

As plants have varied ability to accumulate different metal pollutants, and most adulterated areas have combined pollution, it's necessary to assess the general performance of plants in terms of metal accumulation for phytoremediation practice. Phytoremediation refers to the biotechnologies that wield living plants to wash up habitat-soil, water, and air adulterated with hazardous chemicals. Phytoremediation may be a complex technology which comprises several techniques with reference to the specificity in physiological, morpho-anatomical, biochemical, and molecular responses of plants to excessive concentrations of various contaminants (Pajevic *et al.,* 2016). The phytoremediation of heavy metals may be a cost-effective, efficient, environment- and eco-friendly 'green' technology supported the wield of metal-accumulating plants to prolong poisonous metals, including radionuclides also as organic pollutants from adulterated soils and water (Ali *et al.,* 2013). The goal of soil focused phytoremediation often has got to do with the presence of heavy metals such lead (Pb), mercury (Hg), chromium (Cr), cadmium (Cd) and arsenic (As). The phytoremediation process depends on many factors like heavy metal properties, soil properties and plant species (Laghlimi *et al.,* 2015). The choice of plants to be used as remediating plants is that the most vital factor affecting the efficiency of the phytoremediation process. However, phytoremediation requires high biomass produce, perennial, easily manageable plants that would accumulate more amounts of metals. Therefore, many researchers have dedicated to trying to find plant resources with strong heavy metal tolerance, rapid climb, high biomass and certain heavy metal accumulation ability for phytoremediation (Yang *et al.,* 2008).

From the above view points, this study takes an effort to depict the subsequent objectives:

- To review of different potential plant species having ability to uptake heavy metals from contaminated soils.
- To review of improvement of the utilization of phytoremediation to reduce the quantity of heavy metals in contaminated soils.

CHAPTER II

MATERIALS AND METHODS

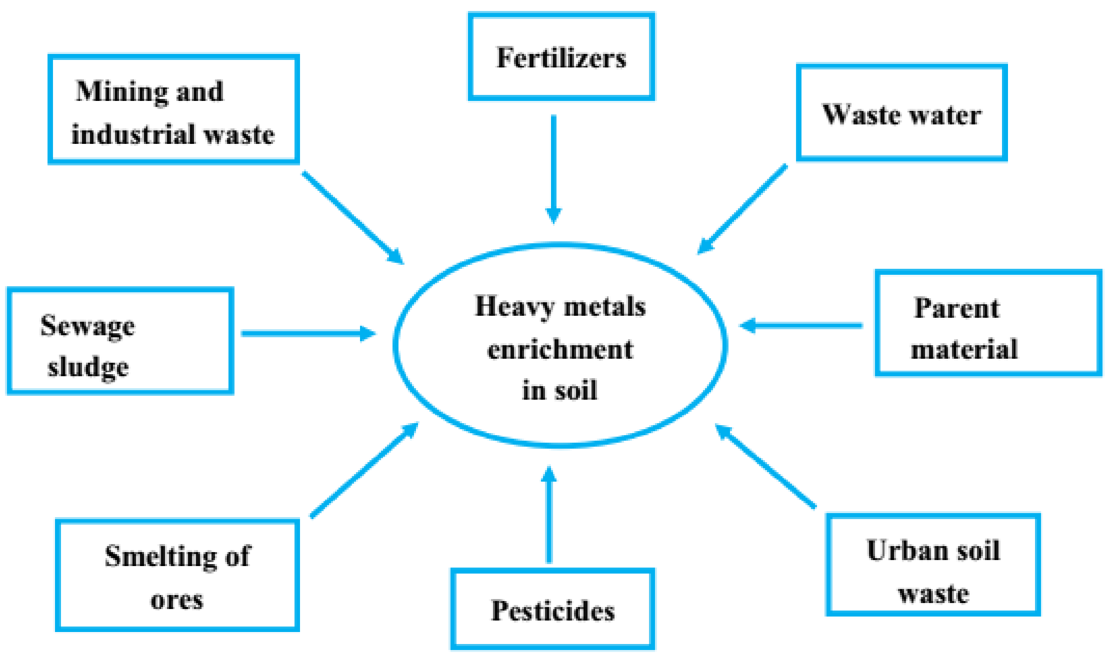
This seminar paper is exclusively a review paper, so all of the information has been collected from secondary sources. Different published reports of various journals mainly supported in providing data for this paper. It's been prepared by comprehensive studies of varied articles published in several journals, books and proceedings available within the libraries of Bangabandhu Sheikh Mujibur Rahman Agricultural University (BSMRAU), Bangladesh Agricultural Research Institute (BARI), Bangladesh Forest Research Institute (BFRI), Bangladesh Agricultural Research Council (BARC). Different information has been collected through contact with respective persons, major professor and Internet facilities to complement this information. All the information collected from the secondary sources have been compiled systematically and chronologically to enrich this seminar paper.

CHAPTER III
REVIEW OF FINDINGS

3.1 Sources of heavy metals in soil environment

Heavy metals in the earth originate from common and anthropogenic sources. The most common sources are minerals enduring, disintegration and volcanic action, while anthropogenic sources are mining, refining, electroplating, the utilization of pesticides and manures in farming, slime dumping, mechanical release, climatic testimony, and so on (Ali *et al.,* 2013).

Heavy metal defiled soil is a genuine worry in many nations. Natural restoration of the defiled soils in the mechanical, rural, and urban domains (Fig. 1) is an incredible test in late decades because of anthropogenic sources (Mahar *et al.,* 2016).



(Source: Mahar *et al.,* 2016)

Fig. 1: Major sources of heavy metals in soil.

Rapid industrialization and consumer lifestyle have led to an unprecedented increase in such toxic in natural ecosystems. Although several long term health effects of heavy metals are well known for a long time, exposure to these toxic substances is continue and even increasing in some parts of the world, particularly in developing and/or less developed countries. Heavy metals contamination happens both at the creation level just as the end utilization of items and run-off in businesses (Table 1) (Marg, 2011).

Table 1. Major uses and sources of soil contamination

Metal	Industry
Chromium (Cr)	Mining, industrial coolants, chromium salts manufacturing, leather tanning etc.
Lead (Pb)	Lead acid batteries, paints, E-waste, Smelting operations, coal-based thermal power plants, ceramics, bangle industry etc.
Mercury (Hg)	Thermal power plants, fluorescent lamps, hospital waste (damaged thermometers, barometers, sphygmomanometers), electrical appliances etc.
Arsenic (As)	Natural processes, smelting operations, thermal power plants, fuel burning etc.
Cadmium (Cd)	Zinc smelting, waste batteries, e-waste, paint sludge, incinerations, fuel combustion etc.

(Source: Modified, Marg, 2011)

3.2 Status of heavy metals in soil environment

Soils in Bangladesh polluted by heavy metals are found to be impacted by various pollution sources (Table 2).

Table 2. Status of heavy metals pollution in Bangladesh soil (mg/kg)

Location	Sampling site	Arsenic (As)	Lead (Pb)	Cadmium (Cd)	Chromium (Cr)
Dhaka (Hazaribagh)	Leather industrial area	1.94	50.32	0.45	976
Dhaka (City area)	High traffic areas	NA	45.68	0.38	31.75
Dhaka (DEPZ), Dry Season	Farm land surrounding	4073.1	27.6	0.0072	49.66
Dhaka (DEPZ), Wet Season	Firm land surrounding	2326.2	9.61	1.04	34.2
Gazipur (City area)	High industrial and traffic areas	NA	27.95	0.41	29.21
Bogra (City area)	Urban and industrial areas	NA	9.61	6.95	4.05
Chittagong (City area)	Industrial and high traffic areas	NA	7.33	2.43	NA
Barisal	Surrounding cement industry	2.13	23.39	0.62	38.26
Barisal	Surrounding textile industry	1.41	18.48	1.9	132.5
Barisal	Surrounding medicine industry	1.67	11.42	0.78	25.73
Kurigram (Chilmari)	Bank of Brahmaputra river	NA	26.7	0.48	34.7
Tangail (Tarutia)	Industrial area	6.11	17.46	2.01	11.56
Dinajpur (Barapukuria)	Mine affected paddy field soil	22.44	188.61	NA	NA
Dinajpur (Barapukuria)	Mine affected farmland soil	17.55	433	NA	NA
Pabna (Pakshi)	Commercial and residential areas	4200	21.29	0.1	28.194
Standards		0.11	200	0.48	11

Notes: NA, not applied/reported; DEPZ: Dhaka Export Processing Zone.

(Source: Modified, Mottalib *et al.,* 2016; Halim *et al.,* 2015; Rahman *et al.,* 2012; Alamgir *et al.,* 2015; Begum *et al.,* 2014; Bhuiyan *et al.,* 2010 ; Alamgir *et al.,* 2015 Tasrina *et al.,* 2015; USEPA, 2002)

3.2.1 Arsenic (As) content status in soil

Industrial wastes and chemical pesticides have added to soil arsenic (As) contamination in Bangladesh. In urban areas, untreated effluents from industries are directly adding heavy metals into the nearby water and soil. Various examinations on farmland accessible the Dhaka Export

Processing Zone (DEPZ) demonstrated that water system with tainted sewage water expanded soil heavy metals (Rahman *et al.,* 2012). Results by Rahman *et al.,* 2012 demonstrated that within the season agricultural soil nearby the Dhaka Export Processing Zone (DEPZ) contained 4073.1 mg/kg of arsenic (As). Excessive use of phosphate fertilizers and pesticides are liable for increasing heavy metals and within the soils of economic and residential vegetable plots in Pakshi, Pabna (Fig. 2) (Tasrina, *et al.,* 2015).

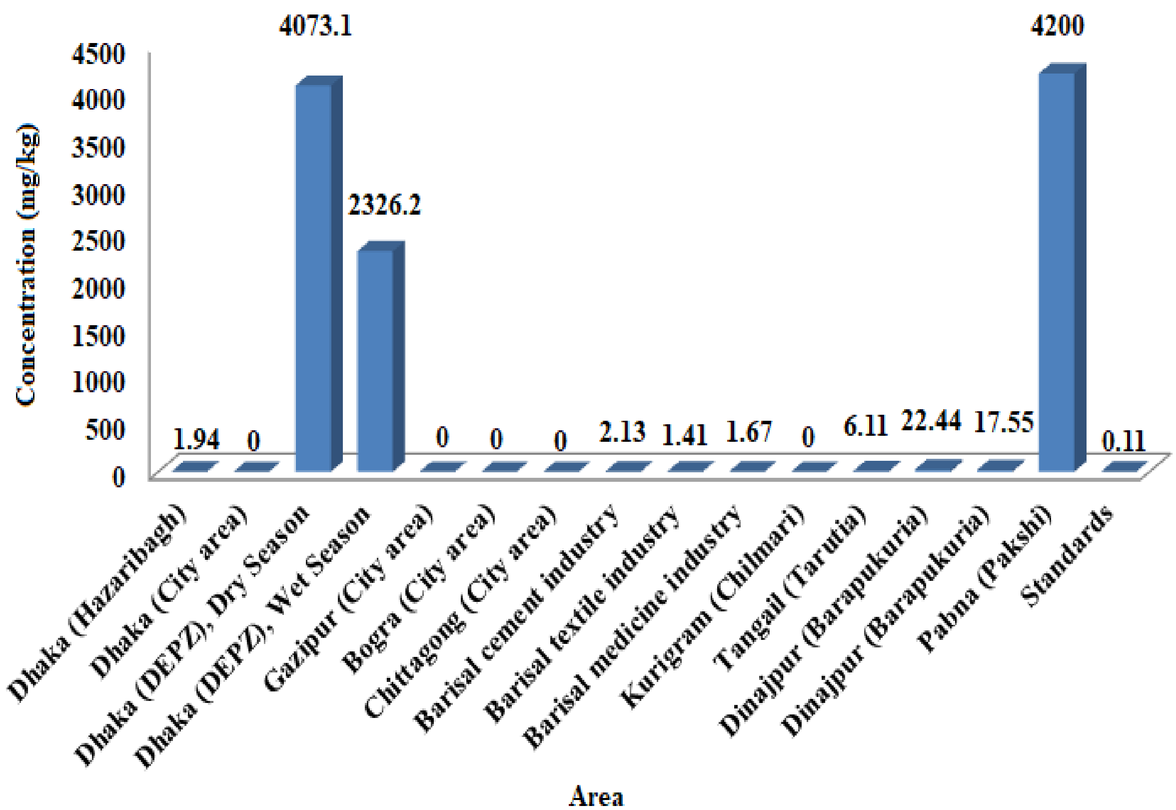


Fig. 2: Arsenic (As) content status in soil.

(Source: Modified, Mottalib *et al.,* 2016; Halim *et al.,* 2015; Rahman *et al.,* 2012; Alamgir *et al.,* 2015; Begum *et al.,* 2014; Bhuiyan *et al.,* 2010 ; Alamgir *et al.,* 2015 Tasrina *et al.,* 2015; USEPA, 2002)

3.2.2 Lead (Pb) content status in soil

In some parts of Bangladesh, mining is highly affected by ground metals. Coal, coal debris and coal-fired boilers affect natural lead (Pb). Soil from the coal mine-affected farm at Barapukuria in Dinajpur contains 433 mg/kg of lead (Pb) (Fig. 3) (Bhuyan *et al.,* 2010).

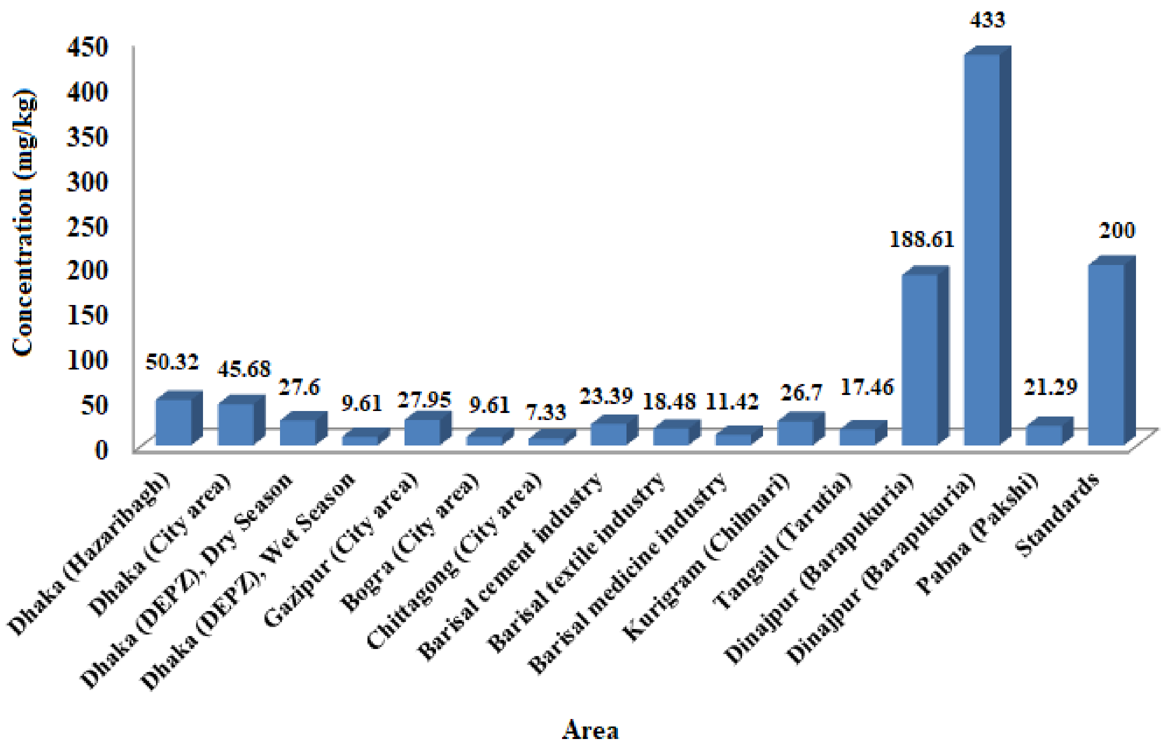


Fig. 3: Lead (Pb) content status in soil.

(Source: Modified, Mottalib *et al.,* 2016; Halim *et al.,* 2015; Rahman *et al.,* 2012; Alamgir *et al.,* 2015; Begum *et al.,* 2014; Bhuiyan *et al.,* 2010 ; Alamgir *et al.,* 2015 Tasrina *et al.,* 2015; USEPA, 2002)

3.2.3 Cadmium (Cd) content status in soil

Industrial and urban waste releases large quantities of heavy metals, which can cause heavy metals in the soil and water. The soils of Chittagong and Bogra cities have been found to be contaminated with cadmium (Cd), mainly due to rapid industrialization and urbanization in recent decades (Fig. 4) (Begum *et al.,* 2014; Alamgir *et al.,* 2015). The soils of many industrial areas in Gazipur, Tangail and Barisal have presented far more classes than recommended values (Zakir *et al.,* 2015).

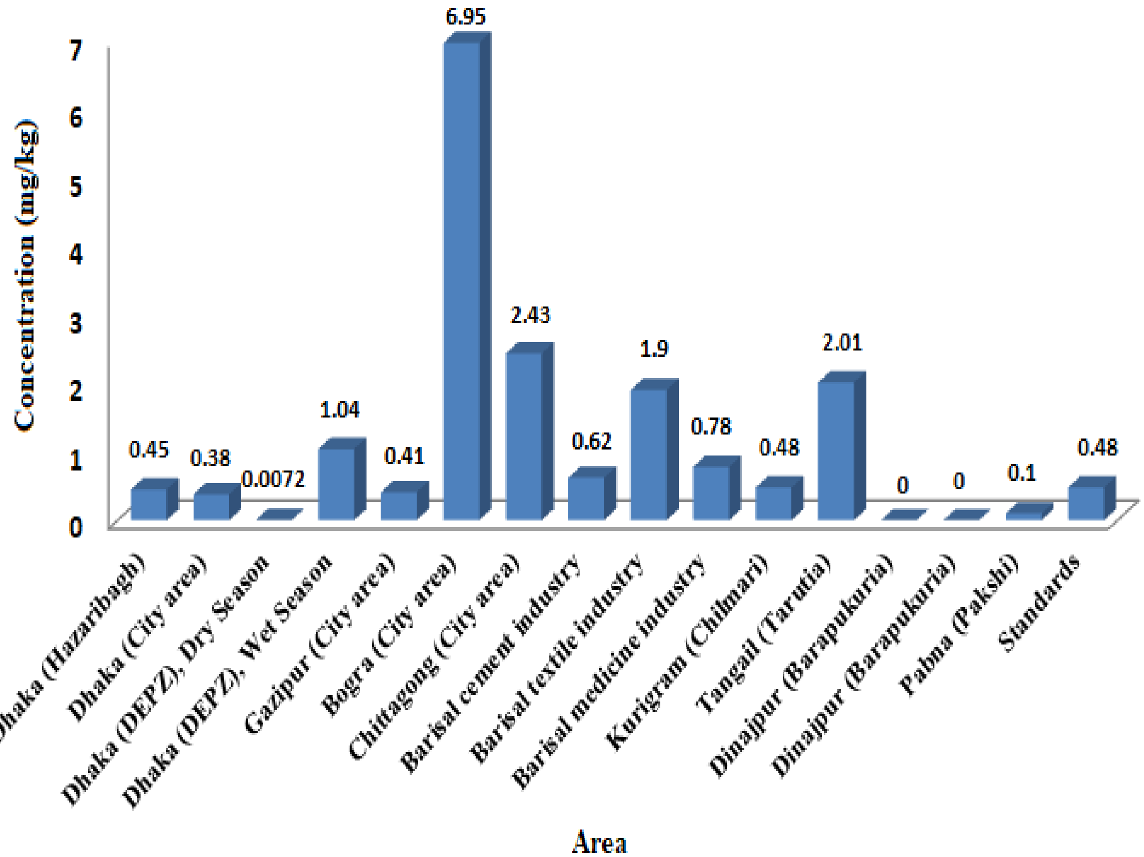


Fig. 4: Cadmium (Cd) content status in soil.

(Source: Modified, Mottalib *et al.,* 2016; Halim *et al.,* 2015; Rahman *et al.,* 2012; Alamgir *et al.,* 2015; Begum *et al.,* 2014; Bhuiyan *et al.,* 2010; Alamgir *et al.,* 2015 Tasrina *et al.,* 2015; USEPA, 2002)

3.2.4 Chromium (Cr) content status in soil

Hasnin *et al.,* (2017) Stated that agricultural areas near Dhaka Export Processing Zone (DEPZ) exhibited 2753.2 mg/kg chromium (Cr) concentrations in surface soils and 1039.2 mg/kg in the surface layer. The results showed that Dhaka Export Processing Zone (DEPZ) contained 49.66 mg/kg chromium (Cr) in agricultural land during the dry season. Due to high chromium (Cr) (976 mg/kg) concentrations in local soils, sewage from the Hazaribagh leather industrial area in Dhaka has been attributed (Fig. 5) (Mottalib *et al.,* 2017).

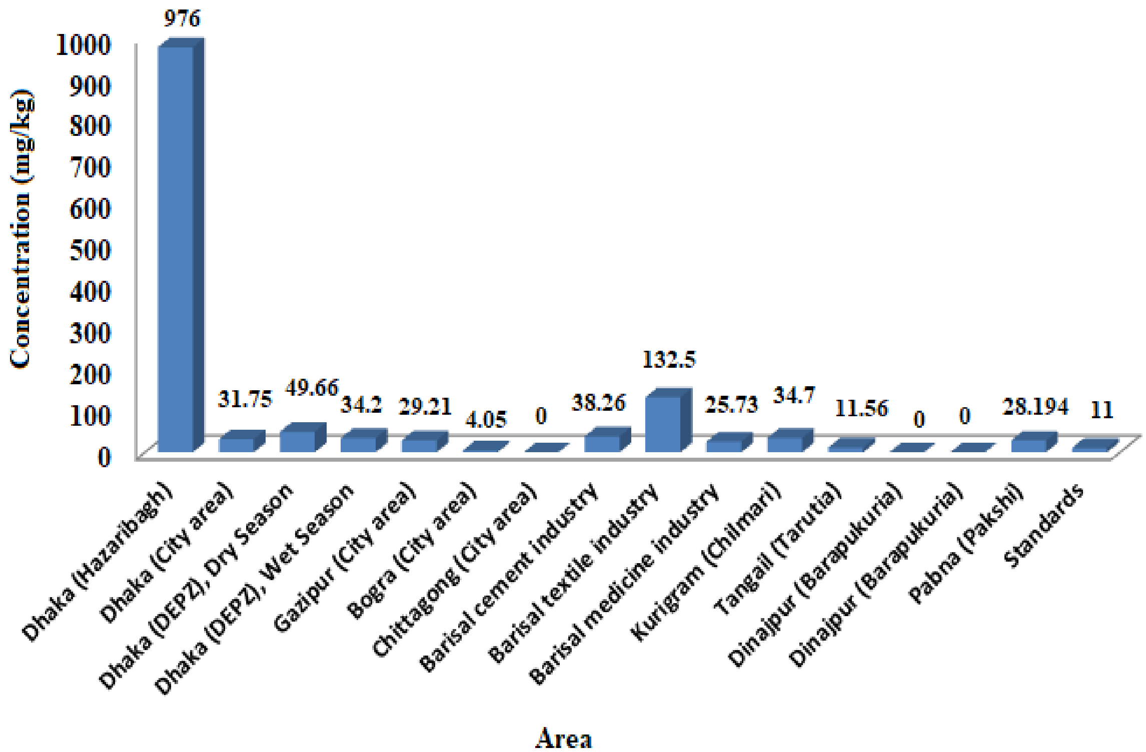


Fig. 5: Chromium (Cr) content status in soil.

(Source: Modified, Mottalib *et al.,* 2016; Halim *et al.,* 2015; Rahman *et al.,* 2012; Alamgir *et al.,* 2015; Begum *et al.,* 2014; Bhuiyan *et al.,* 2010; Alamgir *et al.,* 2015 Tasrina *et al.,* 2015; USEPA, 2002)

3.3 Harmful effects of heavy metals

3.3.1 Effects on soil

Heavy metals are considered one of the main sources of soil pollution. The adverse effects of heavy metals on the biological and biochemical properties of soils. Heavy metals have led to a decrease within the abundance of bacterial species and a relative increase in soil actinomycetes. Enzyme activity is affected by different metals due to the different chemical properties of the enzymes in the soil system (Karaka *et al.,* 2010). Cadmium (Cd) is more toxic to enzymes than lead (Pb) because of its mobility and low affinity for clay colloids. Phosphatase and sulfatase are blocked by arsenic (As), but the disease remains unaffected. Chromium (Cr) is a strong oxidizing agent and is highly toxic. In general, the increase in metal density negatively affects soil microbial properties, which appear to be very useful indicators of soil pollution.

3.3.2 Effects on plants

The absorption and accumulation of heavy metals in plant tissues depends on many factors including temperature, humidity, organic matter, pH and nutrient availability. Elevated lead (Pb) within the soil reduces soil productivity and low lead (Pb) concentration may inhibit some vital plant processes, like photosynthesis, mitosis and water absorption with toxic symptoms of dark green leaves, wilting of older leaves, stunted foliage and brown short roots (Bhattacharyya *et al.,* 2008).

3.3.3 Effects on aquatic environment

Heavy metals are very stable, trace amounts are toxic and induce severe oxidative stress in aquatic organisms. Contamination of a river with heavy metals features a devastating effect on the ecological balance of the aquatic environment and therefore the diversity of aquatic organisms is restricted to the extent of pollution (Ayandiran *et al.,* 2009).

3.3.4 Effects on human health

The effects of heavy metals on human health have been known for a long time alongside with the exposure and increase of heavy metals pollution in the environment. The toxic effects of different heavy metals on human health as summarized by Ali *et al.,* (2013) are presented in Table 3.

Table 3. Toxic effects of some heavy metals on human health

Heavy metals	Regulatory limit (ppm)	Toxic effects
Arsenic (As)	0.01	Affects essential cellular processes such as oxidative phosphorylation and ATP synthesis
Lead (Pb)	15.00	Excess exposure in children causes impaired development, reduced intelligence, short-term memory loss, renal problems
Cadmium (Cd)	5.00	Carcinogenic, mutagenic, endocrine disruptor, lung damage and fragile bones, affects calcium regulation in biological systems
Chromium (Cr)	0.10	Causes hair loss,
Mercury (Hg)	2.00	Causes anxiety, autoimmune diseases, depression, current infections, insomnia, loss of memory, restlessness, disturbance of vision, tremors, brain damage, lung and kidney failure.

(Source: Modified, Ali *et al.,* 2013 and Dixit *et al.,* 2015)

3.4 Phytoremediation mechanisms of heavy metal uptake by plant

The main application of phytoremediation for contaminated soils, where the treated material is shallow or moderate in depth and the area to be treated is large. Plants that are able to contaminate soils does one or more of the following:

1) Plant uptake of contaminant from soil particles or soil fluids into their roots;

2) Bind the contaminant to their root tissues physically or chemically; and

3) Move the contaminated from roots to growing shoots and stop contaminated soil from coming out.

Reduction of heavy metals by the plant through phytoremediation uses these mechanisms of phytoextraction, phytostabilization, rhizofiltration, phytovolatilization and phytodegradation as shown in Fig. 6**.**

3.4.1 Phytoextraction: Phytoextraction is that the uptake/absorption and translocation of contaminants by plant roots into the above ground portions of the plants (shoots) which will be harvested and burned gaining energy and recycling the metal from the ash.

3.4.2 Phytostabilization: Phytostabilization is the use of certain plant species that dissolve contaminants in soil and groundwater by absorption and accumulation in plant tissues, absorption into roots, or migration the root zone preventing their migration in soil, as well as their movement by erosion and deflation.

3.4.3 Rhizofiltration: Rhizofiltration means the absorption or absorption of plant roots and the solution around the root zone created by the wetland to purify religious waste water.

3.4.4 Phytovolatization: Phytovolatization is the refraction and evaporation of a plant by pollution, leaving a contaminated or modified form from the plant to the environment. Some of these contaminants can pass through the plants to the leaves and volatilize into the atmosphere at comparatively low concentrations.

3.4.5 Phytodegradation: Phytodegradation is the breakdown of contaminants in plants by the plant's metabolic processes. Complex organic contaminants are broken down into simple molecules and together with plant tissues accelerate plant growth. (Erakhrumen and Agbontalor, 2007).

In phytoremediation, the root zone is of particular interest. Contaminants can be absorbed by the plant and then stored or metabolized by the root. Another phytoremediation mechanism is the depletion of contaminants in the soil by plant enzymes derived from the roots (Merkl *et al.,* 2007).

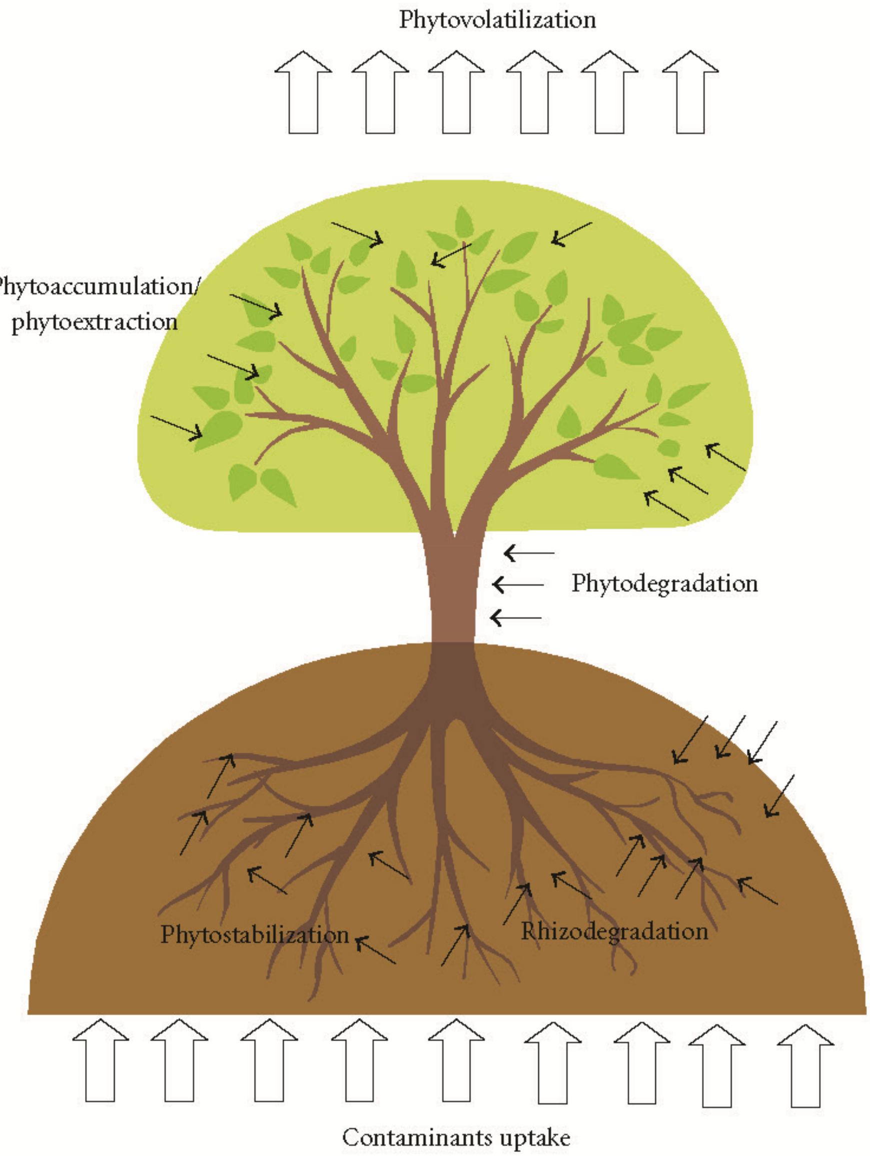


Fig. 6: Mechanisms of heavy metals uptake by plant through phytoremediation.

(Source: Erakhrumen and Agbontalor, 2007)

3.5 Phytoremediation in Bangladesh

A number of plants distributed are observed to be growing at the contaminated areas in Bangladesh. The list of plants used for phytoremediation is shown in Table 4.

Table 4. Plants observed to be growing in contaminated site in Bangladesh

English name	Botanical name	Family
Coat buttons	*Tridax procumbens*	Asteraceae
Hard fern	*Blechnum orientale*	Blechnaceae
Purple cleome	*Cleome rutidosperma*	Cleomaceae
Spiderwort	*Commelina benghalensis*	Commelinaceae
Bindweed	*Evolvulus nummularius*	Convolvulaceae
Asthma	*Euphorbia hirta*	Euphorbiaceae
Leafflower	*Phyllanthus urinaria*	Euphorbiaceae
Dondokolosh	*Leucas aspera*	Lamiaceae
Neem	*Azadirachta indica*	Meliaceae
White Fig	*Ficus infectoria*	Moraceae
Purslane	*Portulaca oleracea*	Portulacaceae

(Source: Azam *et al.,* 2014)

A study conducted by Freeland *et al.* (1974) discussed that *Momordica charantia* has shown to hyperaccumulate copper (Cu), cadmium (Cd) from such metal-contaminating soils and *Tridax procumbens* leaves have ability to accumulate mercury (Hg). In another study, Sekabira *et al.* (2011) reported that *Blechnum orientale* has the ability to accumulate lead (Pb) from soil and *Commelina benghalensis* can accumulate copper in shoots and lead (Pb), cadmium (Cd) in the roots. However, Nazi *et al.* (2011) reported that 76.8 and 41.45% of leaves aqueous solutions *Azadirachta indica* can remove copper (Cu) and lead (Pb), respectively.

3.6 Heavy metal concentrations in leaf and bark

Heavy metals concentrations in the leaf and bark of trees is differ with season. The peak heavy metal concentrations were observed in the leaves and bark of most species during the summer. These results could also be associated with the more atmospheric precipitations in spring and autumn which may wash out the particulate matters from the surfaces of the leaves and barks. Moreover, the mean of heavy metals concentrations within the barks were significantly quite those for leaves. the foremost probable explanations for this difference are these facts that barks can retain their structure against the pollutants for extended time, they're widely available without affecting the health of the trees, and porosity structure of bark is extremely high (Sawidis *et al.,* 2011).

3.6.1 Lead (Pb) concentration in leaf and bark of different trees

The sufficient lead (Pb) concentration in the plants are often within the range of 5-10 mg/kg and its toxic concentrations is from 30 -300 mg/kg. The toxic lead (Pb) range for plants to be between 3-20 mg/kg. In present study, the minimum seasonal mean lead (Pb) concentration within the leaf and bark were related to *Fraxinus excelsior* and *Ulmus umbraculifera*, respectively, and its maximum in leaf and bark were associated in *Pinus eldarica* and *Alnus glutinosa*, respectively. The lead (Pb) concentrations in plants are typically less than 10 mg/kg (Fig. 7) (Hu *et al.,* 2014).

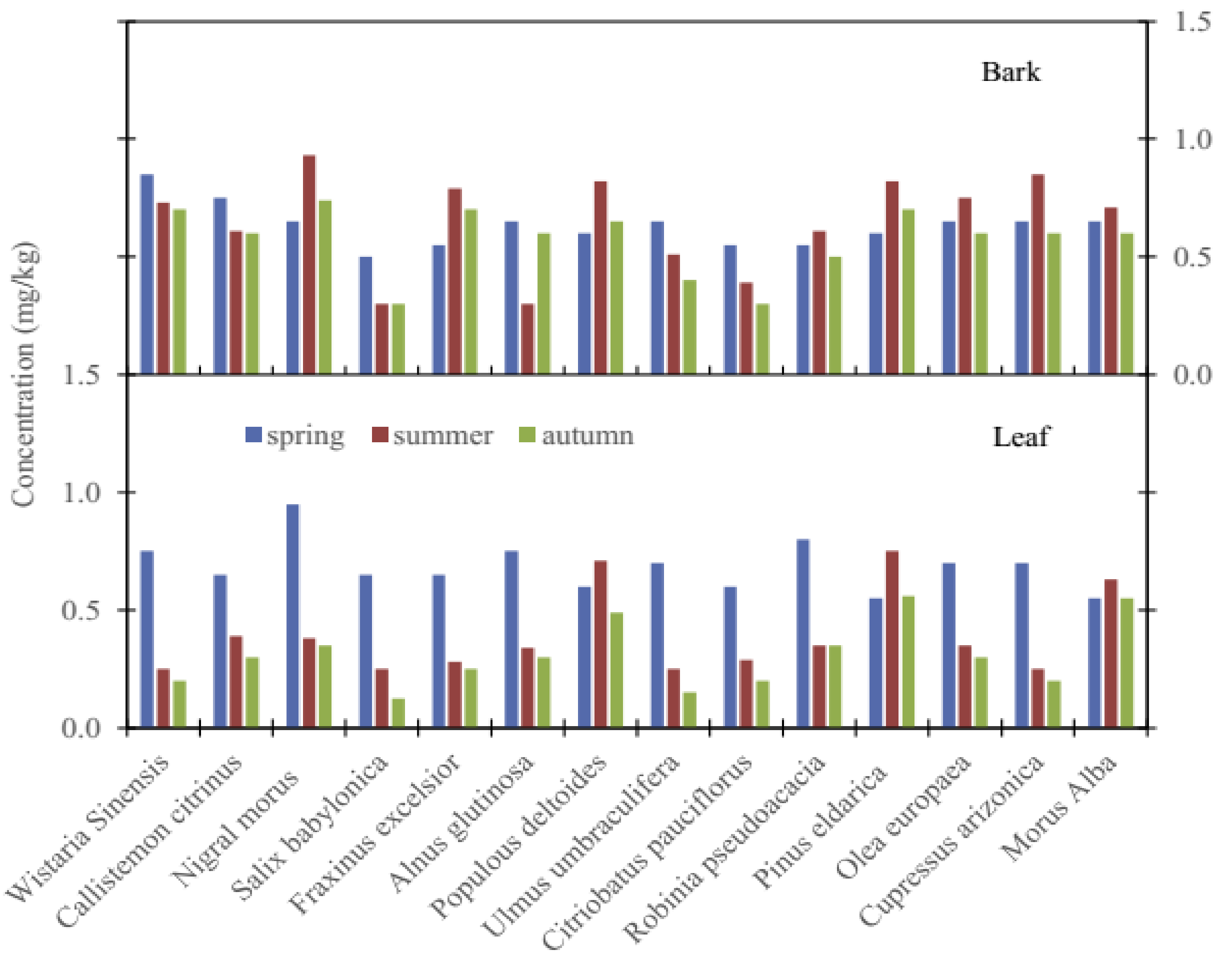


Fig. 7: Lead (Pb) concentration in leaf and bark of different trees.

(Source: Hu *et al.,* 2014)

3.6.2 Cadmium (Cd) concentration in leaf and bark of different trees

The seasonal mean density of cadmium (Cd) is 0.34–0.62 mg/kg for bark. Maximum average cadmium (Cd) concentrations for leaf and bark were observed in *Pinus aldarica* and *Nigral maurus*, respectively. For both leaf and bark, the minimum concentration was found *Salix babilonica* (Fig. 8). In general, cadmium (Cd) concentrations in plants are less than 10 mg/kg. Low concentrations of cadmium (Cd) are present in particular cases, which is the main reason for low cadmium (Cd) concentrations in plant samples (Hu *et al.,* 2014).

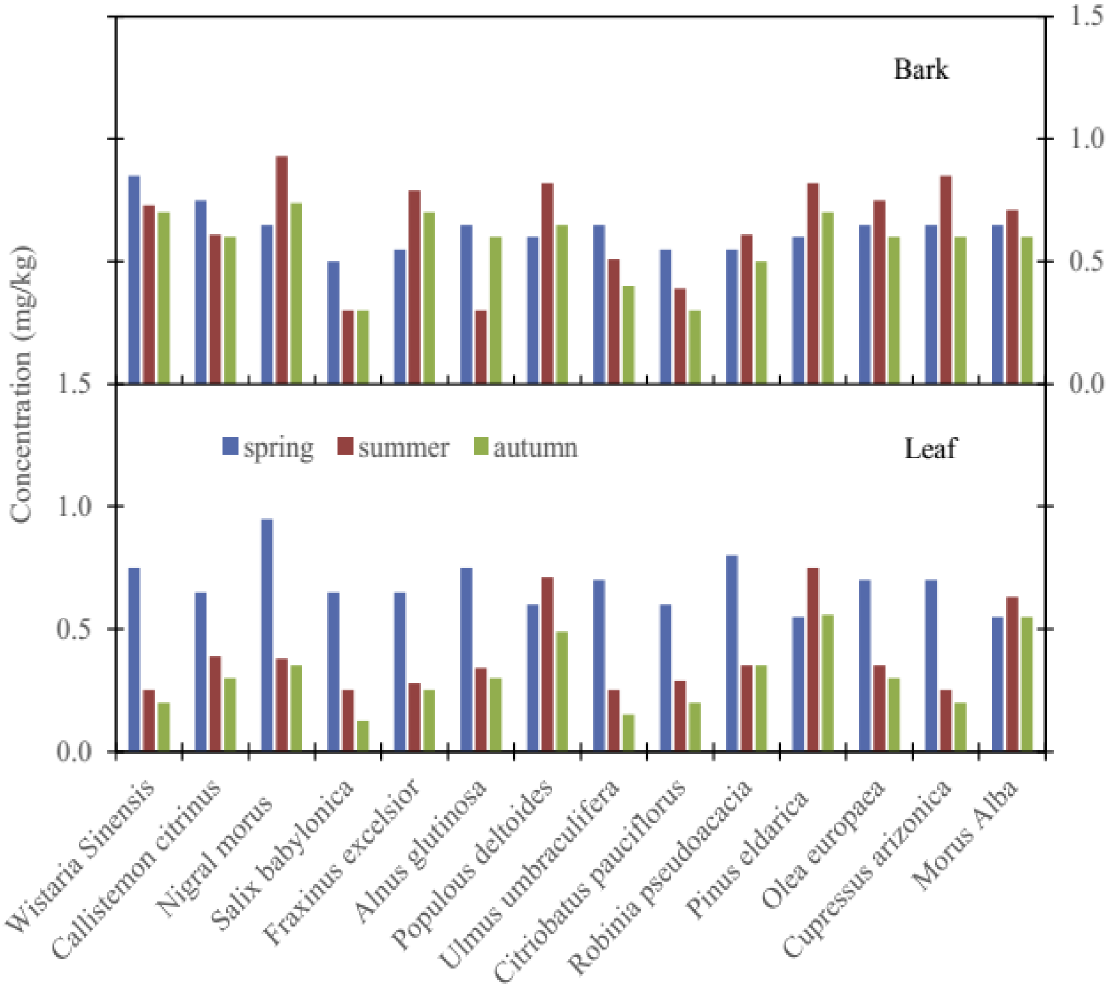


Fig. 8: Cadmium (Cd) concentration in leaf and bark of different trees.

(Source: Hu *et al.,* 2014)

3.7 Accumulation of heavy metals in plant tissue

Based on the collected data from the phytoremediation research, the accumulation of heavy metals arsenic (As) and mercury (Hg) in plant tissue is summarized in respective, Fig. 9 and 10.

3.7.1 Accumulation of arsenic (As) in plant tissue

According to Fig. 9, the highest accumulation of arsenic (As) in plant tissue (the researchers have not detailed which part it is, but it might be the whole plant) occurs in *Pteris vittata* species. It can reach more than 0.7 mg As/g dry weight of plant. In plant root, the highest accumulation of arsenic (As) is in *Populus nigra*, which can reach more than 0.2 mg As/g dry weight of plant root (Coleman and Ronald, 2006).

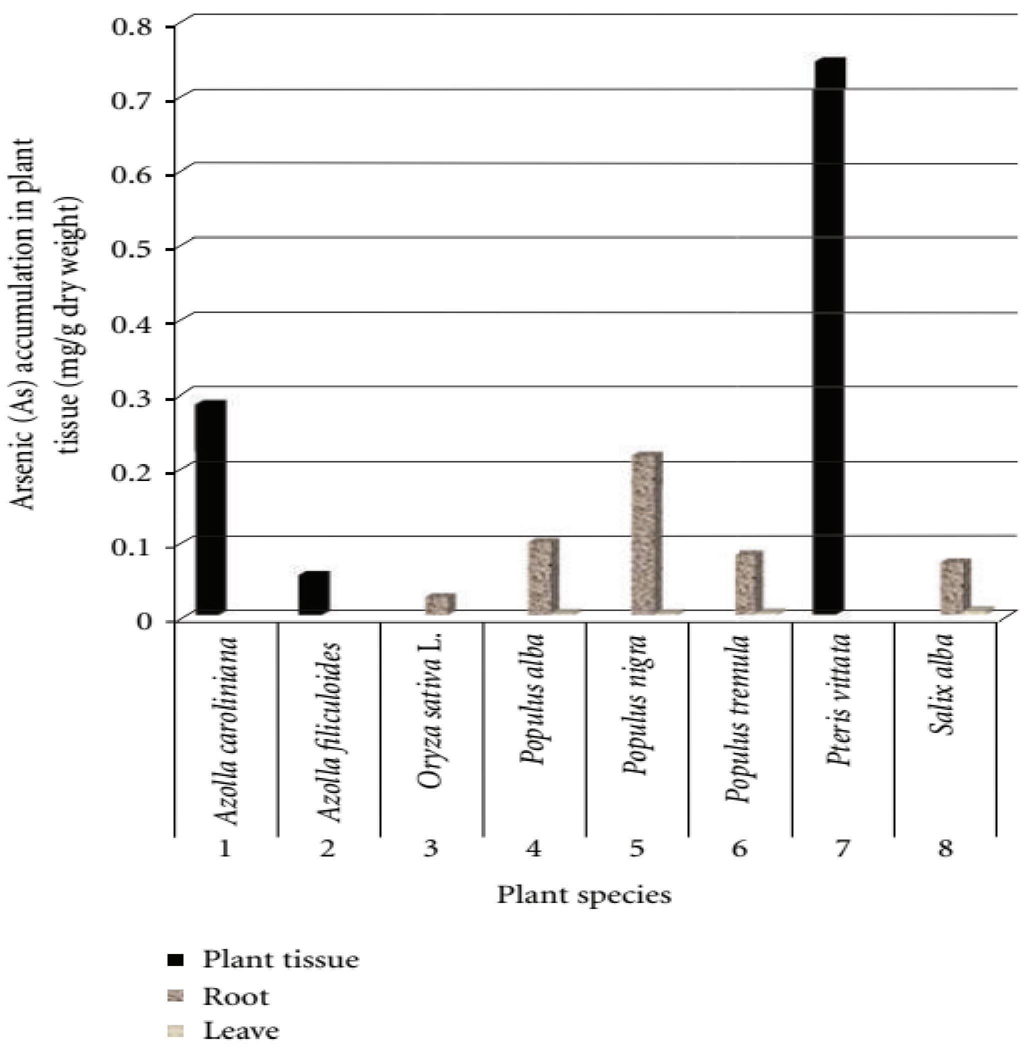


Fig. 9: Arsenic (As) accumulation in plant tissue.

(Source: Coleman and Ronald, 2006)

3.7.2 Accumulation of mercury (Hg) in plant tissue

Fig. 10 shows that accumulated Mercury (Hg) in *Brassica juncea* (L.) Czern. is much higher than in other species of plants. It could reach more than 1 mg Hg/g dry weight of plant while the other plants only accumulate less than 0.2 mg Hg/g dry (Coleman and Ronald, 2006).

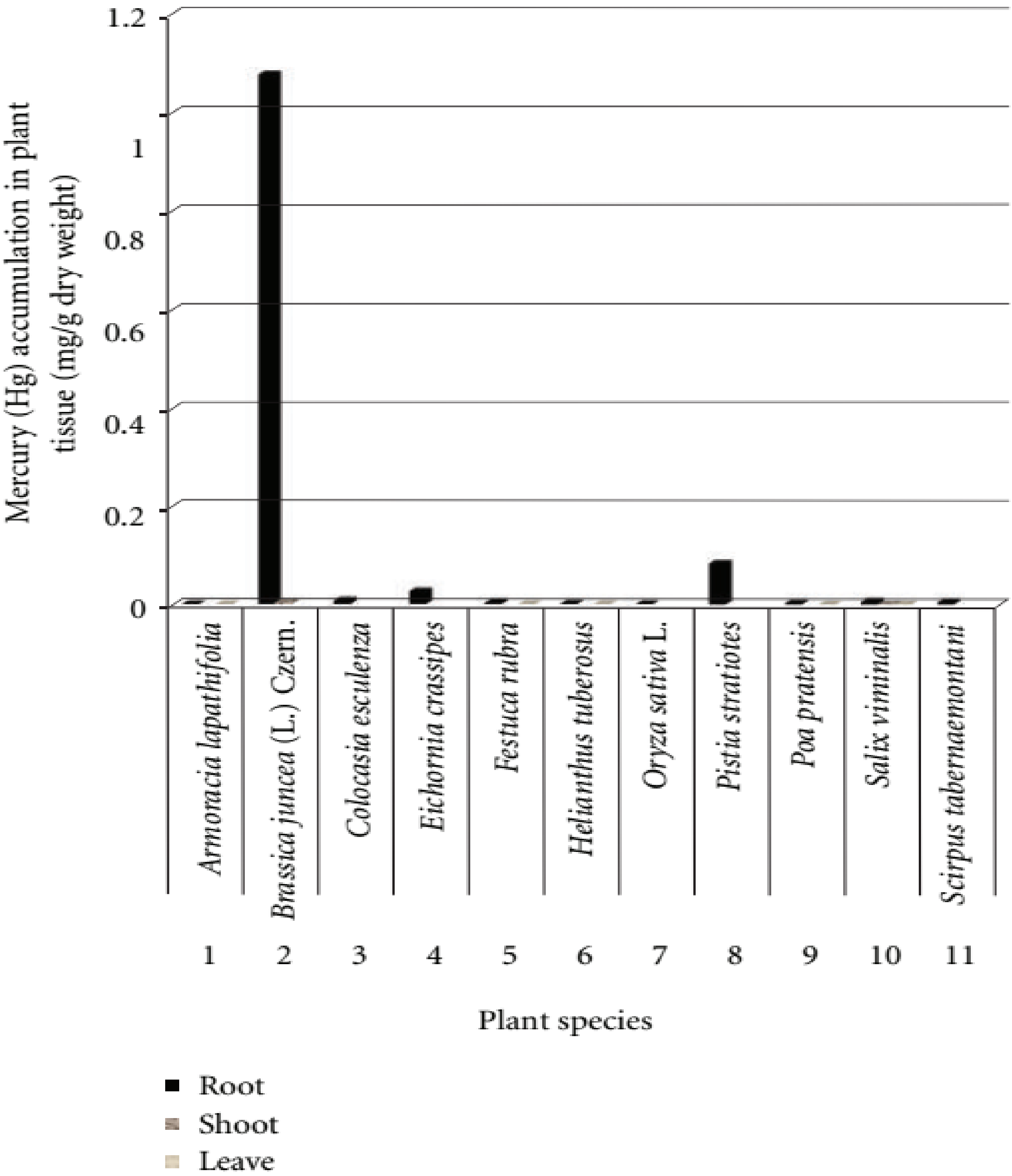


Fig. 10: Mercury (Hg) accumulation in plant tissue.

(Source: Coleman and Ronald, 2006)

Generally, heavy metals concentration in different plant parts is depended on the amount of heavy metals in the air and soil, and it is different within and between species of plants.

CHAPTER IV
CONCLUSIONS

Phytoremediation technology has been found one of the best potential options of uptaking/removing heavy metals from contaminated soils compared to the commonly used methods. Although the success of the phytoremediation process depends on many factors like heavy metal properties, soil properties and plant species. Even the accumulation ability of leaf and bark of the same plant species with the same heavy metals concentrations is different.

Pinus eldarica and *Wistaria sinensis* had the highest ability to accumulate heavy metals from soil. The maximum values of lead (Pb) and Cadmium (Cd) for leaves were found in *Pinus eldarica* then *Morus alba*, and for barks the maximum values of lead (Pb) and Cadmium (Cd) were found in *Morus alba*, *Buxushyrcana* and *Nigral morus* species. Therefore, these species can be used as a good bioaccumolator for heavy metals. The highest accumulation of arsenic (As) in plant tissue occurs in *Pteris vittata* species that accumulated Mercury (Hg) in *Brassica juncea* (L.) Czern. is much higher than in other species of plants.

Phytoremediation technology is still in its early development stage and full-scale applications are still limited. Findings from different reviews indicated that there is huge potentials to study in this field for screening of suitable species as well as identifying specific plant part which could accumulate specific heavy metals.

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