PHYSICO-CHEMICAL STUDIES ON PHYTO FILTRATION OF HEAVY METALS BY CERTAIN INDIGENOUS PLANTS

Jisha Undarathi

Abstract— Plant samples were separately harvested after 7, 21 and 30 days to analyse for growth rate and metal content. The experiments were set up in triplicate for each condition.The uptake of heavy metals can be estimated by Atomic Absorption Spectrophotometer by digesting the harvested plant parts in a suitable medium. Medium for digestion is a challenge and trial and error method has conducted for that. By knowing the concentration of heavy metal accumulated in root, shoot and aerial part the bio concentration factor and the translocation factor can be calculated.

Index Terms— Aerva lanata, biosorbent, cadmium nitrate, Centella asiatica, Coleus aromaticus, heavy metal sorption, lead nitrate.

1 Introduction

THE water contamination is an unavoidable evil. It is clear that the process of contamination of water and its natural decontamination started from the day one when the water might have formed. At the global scale this problem appears less important when compared to the pressing issues of air pollution. However the fact remains that the sources of fresh water are very limited and the geographical compulsions make it almost impossible to get alternatives. Water contamination has many causes. Almost all human activities and specifically activities such as fuel and industrial-chemical use, hard-rock mining, fertilizer application, and land disposal of solid waste and wastewater can introduce organic and inorganic contaminants into the surface and subsurface water. Once these contaminants reach the subsurface water they are carried by flowing ground water and can eventually reach water supplies, streams, lakes, and the ocean. Many physical, chemical, and biological processes alter and disperse contaminants in the subsurface.

Many industries such as tannery, coating, car, aeronautic and steel industries generate great quantities of wastewater containing various concentrations of Cu, Zn and Cr. These concentrations are usually too low to be treated by standard methods. The main techniques that are commonly used for the recovery of metal ions from industrial effluents include precipitation, coagulation-adsorption, ion exchange, membrane processing and solvent extraction. These techniques suffer from diverse drawbacks[1]. For example, precipitations processes cannot guarantee the metal concentration limits required by regulatory standards and produce wastes that are difficult to treat. On the other hand, ion exchange and adsorption processes are very effective but require expensive adsorbent materials for the removal of heavy metals from dilute aqueous streams. The use of low-cost and waste materials of biological origins as adsorbents of dissolved metal ions has been shown to provide economic solutions to this global problem.

• ***Jisha undarathi*** *is currently pursuing PhD degree program in chemistry in kannur University, India, PH-09526867618, jishanairforu@gmail.com*

1.2 Definition of a heavy metal

"Heavy metals" are chemical elements with a specific gravity that is at least 5 times the specific gravity of water. The specific gravity of water is 1 at 4 o C (39oF). Simply stated, specific gravity is a measure of density of a given amount of a solid substance when it is compared to an equal amount of water. Some well-known toxic metallic elements with a specific gravity that is 5 or more times that of water are arsenic, 5.7; cadmium, 8.65; iron, 7.9; lead, 11.34; and mercury,13.546[2].Or it is a general collective term, which applies to the group of metals and metalloids with atomic density greater than 4000 kg m3. In small quantities, certain heavy metals are nutritionally essential for a healthy life.

1.3 Beneficial heavy metal

Some of these are referred to as the trace elements (e.g., iron, copper, manganese, and zinc). These elements, or some form of them, are commonly found naturally in foodstuffs, in fruits and vegetables, and in commercially available multivitamin products (International Occupational Safety and Health Information Centre 1999). Diagnostic medical applications include direct injection of gallium during radiological procedures, dosing with chromium in parenteral nutrition mixtures, and the use of lead as a radiation shield around x-ray equipment [3]Heavy metals are also common in industrial applications such as in the manufacture of pesticides, batteries, alloys, electroplated metal parts, textile dyes, steel, and so forth.(International Occupational Safety and Health Information Centre 1999). Many of these productsare in our homes and actually add to our quality of life when properly used.

1.4 Heavy metal contamination and need for their control

Heavy metals are metallic elements that have a high atomic number and are poisonous to living organisms. Approximately 30 metals have been shown to be poisonous to humans. Examples of heavy metals that are poisonous include mercury, chromium, cadmium, arsenic, and lead. Because they are poisonous, heavy metals are sometimes referred to as toxic metals. Heavy metals may be poisonous on their own or as part of chemical compounds. It has been known for centuries that certain metals are toxic. For example, Theophratus of Erebus (370-287 B.C.) and Pliny the Elder (A.D. 23-79) both described poisonings that resulted from arsenic and mercury. Other heavy metals, such as cadmium, were not recognized as poisonous until the early nineteenth century. Heavy metals occur naturally in the environment in rocks and ores. They cycle through the environment by geological and biological means. The geological cycle begins when water slowly wears away rocks and dissolves the heavy metals. The heavy metals are carried into streams, rivers, lakes, and oceans. The heavy metals may be deposited in sediments at the bottom of the water body, or they may evaporate and be carried elsewhere as rainwater. The biological cycle includes accumulation in plants and animals and entry into the food web.

Sometimes these natural cycles can pose a hazard to human health, because the levels of heavy metals exceed the body's ability to cope with them. A further complication is the addition of heavy metals to the environment as a result of human activity. Activities such as mining and manufacturing greatly increase the release of heavy metals from rocks and ores. The activities also create situations in which the heavy metals are incorporated into new compounds and may be spread worldwide. There are 35 metals that concern us because of occupational or residential exposure; 23 of these are the heavy elements or "heavy metals": antimony, arsenic, bismuth, cadmium, cerium, chromium, cobalt, copper, gallium, gold, iron, lead, manganese, mercury, nickel, platinum, silver, tellurium, thallium, tin, uranium, vanadium, and zinc. Interestingly, small amounts of these elements are common in our environment and diet and are actually necessary for good health, but large amounts of any of them may cause acute or chronic toxicity (poisoning). Heavy metal toxicity can result in damaged or reduced mental and central nervous function, lower energy levels, and damage to blood composition, lungs, kidneys, liver, and other vital organs. Long-term exposure may result in slowly progressing physical, muscular, and neurological degenerative processes that mimic Alzheimer's disease, Parkinson's disease, muscular dystrophy, and multiple sclerosis. Allergies are not uncommon and repeated long-term contact with some metals or their compounds may even cause cancer (International Occupational Safety and Health Information Centre 1999).

The heavy metal toxicity is an uncommon medical condition; however, it is a clinically significant condition when it does occur and if unrecognized or inappropriately treated, toxicity can result in significant illness and reduced quality of life. The association of symptoms indicative of acute toxicity is not difficult to recognize because the symptoms are usually severe, rapid in onset, and associated with a known exposure or ingestion; cramping, nausea, and vomiting; pain; sweating; headaches; difficulty breathing; impaired cognitive, motor, and language skills; mania; and convulsions. The symptoms of toxicity resulting from chronic exposure (impaired cognitive, motor, and language skills; learning difficulties; nervousness and emotional instability; and insomnia, nausea, lethargy, and feeling ill) are also easily recognized; however, they are much more difficult to associate with their cause. Symptoms of chronic exposure are very similar to symptoms of other health conditions and often develop slowly over months or even years. Sometimes the symptoms of chronic exposure actually abate from time to time, leading the person to postpone seeking treatment, thinking the symptoms are related to something else.

1.5 Threat from the environment

It has been established that dissolved metals (particularly heavy metals) escaping into the environment pose a serious health hazard. They accumulate in living tissues throughout the food chain which has humans at its top thus multiplying the danger. Heavy metals become toxic when they are not metabolized by the body and accumulate in the soft tissues. Heavy metals may enter the human body through food, water, air, or absorption through the skin when they come in contact with humans in agriculture and in manufacturing, pharmaceutical, industrial, or residential settings. [4]Therefore, it is necessary to control emissions of heavy metals into the environment.

1.6 Need for novel technologies

Conventional techniques to remove toxic metals and radionuclides such as ion exchange and precipitation, lack specificity and are ineffective at low metal ion concentrations. The need for effective and economically viable technologies is driven by environmental pressures such as:

1. Stricter regulations with regard to the metal discharges are being enforced, particularly in industrialized countries.
2. Toxicology studies confirm the dangerous impacts of heavy metals.
3. Current technologies for the removal of heavy metals from industrial effluents often create secondary problems with metal-bearing sludge.

1.7 Biosorption and Phytoremediation: a solution to pollution?

Biosorption and Phytoremediation are the newest topic of research for the industrial and natural toxic contamination. Biosorption relies on the use of dead plant matter having a high affinity for target elements or chemical compounds. Phytoremediation uses the natural attributes of living plants for applications in site remediation efforts. Useful attributes of plants include their roots, which have enormous surface area to bioaccumulate and concentrate contaminants such as heavy metals and other inorganic compounds, and their diverse genetic adaptations to handle toxic levels of contaminants and mineralize toxic organic compounds. Both techniques are considered superior to the traditional pure chemical methods of treatments as they are very expensive and they introduce a different type of pollutant in the environment. In addition, Phytoremediation technologies could possess a positive synergy between microorganisms in the rhizosphere, in that the numbers and activities of microorganisms are increased due to the nutrient and energy sources provided by the plant. In many instances these microbial activities are bioremedial. Thus, Phytoremediation may benefit by living environment, which surrounds it. Overall, in both techniques the main agents are the plants. As the plant cultivation and management is cost-effective and in many ways more easily accepted by the general public, since it is a solar energy driven natural process.

A worldwide workshop was held in 1994 by the US Department of Energy to discuss the current status and the basic and applied research needs of phytoremediation. The potential of metal concentration by certain types of dead biomass has been well established over the last two decades. This phenomenon can probably make the most significant impact in using it for removing toxic heavy metals from industrial effluents. An interdisciplinary approach seems essential for bringing the phenomenon to a successful process application stage. Challenges in the novel biosorption process development are briefly summarized here for scientists and entrepreneurs alike.

1.8 Phytoremediation

Ecosystems have been contaminated with heavy metals due to various human and natural activities. The sources of metals in the soil are diverse including burning of fossil fuels, mining and smelting of metalliferous ores, municipal wastes, fertilizers, pesticides, sewage sludge, the use of pigments and batteries. It is well known that heavy metals cannot be chemically degraded and need to be physically removed or be immobilized. Phytoremediation, the use of plants to remediate or clean up-contaminated soils can be used as a promising method to remove and/or stabilise soils contaminated with heavy metals. Phytoremediation is the use of trees and plants to help clean up toxic waste sites- is not only a growing science; it's also a growth industry. Phytoremediation offers a cost effective, nonintrusive and safe alternative to conventional clean up techniques [5], [6], [7].

1.9 History of phytoremediation

16 century Florentine botanist named Andrea Cesalpino reported that he had noticed the ubiquitous presence of an "alyssum" growing over 'block stone ' (ultramafic rocks) in the Upper Tiber Valley in Tuscany. The plant was later described by Desvaux who named it alyssum bertolonii. After some time another paper by Floentine couple, Minguzzi and Vergnano, described the unusual accumulation of nickel by alyssum bertolonii from the lmpruneta region near Florence. They found up to 0.79 persent (7900 mg/g) nickel in dried leavas of plants growing in soils containing only 0.42% of this element. This original paper elicited little interest and even the discovery of a second "Nickel-Plant", Alyssum mural by a Russian scientist Doksopulo (1961) produced no ripple in the scientific community. Fifteen years later jaffre et al (1976) reported an unusual tree (sebertia acuminata) from New Caledonia, which contained a blue sap ('seve bleue') that was later found to contain about 10% nickel in the fresh material and 20% in the dried sap. This was the most unusual discovery so far made in the field of Nickel Plant". The term "hyper accumulation" was first used in 1977 and since then these unusual species have found a ready application in diverse and seemingly unrelated fields such as mineral exploration and land restoration but the common thread is the highly unusual capacity of a few rare plant to hyper accumulate a number of heavy metals [8].

1.10 Applicability of phytoremediation

Phytoremediation is used for the remediation of metals, radionuclides, pesticides, explosives, fuels, volatile organic compounds (VOCs) and semi-volatile organic compounds (SVOCs). Research is underway to understand the role of Phytoremediation to remediate per chlorate, a contaminant that has been shown to be persistent in surface and groundwater systems. It may be used to clean up contaminants found in soil and groundwater. For radioactive substances, chelating agents are sometimes used to make the contaminants amenable to plant uptake.

1.11 Mechanism

What is phytoremediation Phytoremediation is a bioremediation process that uses various types of plants to remove, transfer, stabilize, and/or destroy contaminants in the soil and groundwater. There are several different types of Phytoremediation mechanisms. These are:

Rhizosphere biodegradation- In this process, the plant releases natural substances through its roots, supplying nutrients to microorganisms in the soil. The microorganisms enhance biological degradationn.

Phyto-stabilization- In this process, chemical compounds produced by the plant immobilize contaminants, rather than degrade them.

Phyto-accumulation (also called phyto - extraction)- In this process, plant roots absorb the contaminants along with other nutrients and water. The contaminant mass is not destroyed but ends up in the plant shoots and leaves. This method is used primarily for wastes containing metals. At one demonstration site, water-soluble metals are taken up by plant species selected for their ability to take up large quantities of lead (Pb). The metals are stored in the plant aerial shoots, which are harvested and either smelted for potential metal recycling/recovery or are disposed of as a hazardous waste. As a general rule, readily bio available metals for plant uptake include cadmium, nickel, zinc, arsenic, selenium, and copper. Moderately bio available metals are cobalt, manganese, and iron. Lead, chromium, and uranium are not very bio available. Lead can be made much more bio available by the addition of chelating agents to soils. Similarly, the availability of uranium and radio-cesium 137 can be enhanced using citric acid and ammonium nitrate, respectively.

Hydroponic Systems for Treating Water Streams (Rhizofi/tration)-Rhizofiltration is similar to phyto-accumulation, but the plants used for clean-up are raised in greenhouses with their roots in water. This system can be used for ex-situ groundwater treatment. That is, groundwater is pumped to the surface to irrigate these plants. Typically hydroponic systems utilize an artificial soil medium, such as sand mixed with perlite or vermiculite. As the roots become saturated with contaminants, they are harvested and disposed of.

Phyto-volatilization- In this process, plants take up water containing organic contaminants and release the contaminants into the air through their leaves. Phyto-degradation-In this process, plants actually metabolize and destroy contaminants within plant tissues. Hydraulic Control. In this process, trees indirectly remediate by controlling groundwater

movement. Trees act as natural a pump when their roots reach down towards the water table and establish a dense root mass that takes up large quantities of water. A poplar tree, for example, pulls out of the ground 30 gallons of water per day and a cottonwood can absorb up to 350 gallons per day. The plants most used and studied are poplar trees. The U.S. Air Force has used poplar trees to contain trichloroethylene (TCE) in groundwater [9],[11],[12].

1.12 Limitations and Concerns

The toxicity and bioavailability of biodegradation products is not always known.

Degradation by-products may be mobilized in groundwater or bio-accumulated in animals.

Additional research is needed to determine the fate of various compounds in the plant metabolic cycle to ensure that plant droppings and products do not contribute toxic or harmful chemicals into the food chain. Scientists need to establish whether contaminants that collect in the leaves and wood of trees are released when the leaves fall in the autumn or when firewood or mulch from the trees is used. Disposal of harvested plants can be a problem if they contain high levels of heavy metals. The depth of the contaminants limits treatment. The treatment zone is determined by plant root depth. In most cases, it is limited to shallow soils, streams, and groundwater. Pumping the water out of the ground and using it to irrigate plantations of trees may treat contaminated groundwater that is too deep to be reached by plant roots. Where practical, deep tilling, to bring heavy metals that may have moved downward in the soil closer to the roots, may be necessary. Generally, the use of Phytoremediation is limited to sites with lower contaminant concentrations and contamination in shallow soils, streams, and groundwater. However, researchers are finding that the use of trees (rather than smaller plants) allows them to treat deeper contamination because tree roots penetrate more deeply into the ground. The success of phytoremediation may be seasonal, depending on location. Other climatic factors will also influence its effectiveness. Some phytoremediation transfers contamination across media, (e.g., from soil to air). Phytoremediation is not effective for strongly absorbed contaminants such as polychlorinated biphenyls (PCBs). Phytoremediation requires a large

surface area of land for remediation.

The main attraction of bio sorption is its cost effectiveness while ion exchange can be considered a 'mature' technology, bio sorption is in its early developmental stages and further improvements in both performance and costs can be expected. The bio sorption can become a good weapon in the fight against toxic metals threatening our environment. While the bio sorption process could be used even with a low degree of understanding of its metal-binding mechanisms, better understanding will make for its more effective and optimized applications[13],[14].

2 SCOPE AND OBJECTIVE OF THE PRESENT STUDY

2.1 Justification of the work

A major environmental concern due to dispersal of industrial and urban wastes generated by human activities is the contamination of soil and water. A wide range of inorganic and organic compounds cause contamination, these include heavy metals, combustible and hazardous wastes, explosives and petroleum products [15],[16],[17]. Major component of inorganic contaminates are heavy metals. They present a different problem than organic contaminants. Microorganisms can degrade organic contaminants, while metals need immobilization or physical removal [18]. Although many metals are essential, all metals are toxic at higher concentration, because they cause oxidative stress [19] by formation of free radicals. Another reason why metals may be toxic is that they can replace essential metals in pigments or enzymes disrupting their function [20].

The chemical technologies generate large volumetric sludge and increase the costs; chemical and thermal methods are both technically difficult and expensive that all of these methods can also degrade the valuable component of the soil. Elimination of toxic pollutants from contaminated water using biomass can take place by phytoremediation and bio accumulation or bio sorption [21]. It can take place with living or dead biomass and it includes adsorption to the biomass and absorption by the biomass. In any case, removal of metals involves extracellular accumulation/precipitation, cell surface adsorption/precipitation, and intra cellular accumulation and can occur by complexation, coordination, chelation of metals, ion exchange adsorption and micro precipitation [22]. Bio sorption of heavy metals, organic pollutants, and pesticides from waste water has been investigated using several plant species including macrophytes.

‘’Phytoremediation basically refers to the use of plants and associated soil microbes to reduce the concentrations or toxic effects of contaminants in the environments’[23]. The term ‘’phytoremediation’’ is a combination of two words: Greek phyto (meaning plant) and Latin remedium (meaning to correct or remove an evil). Green plants have an enormous ability to uptake pollutants from the environment and accomplish their detoxification by various mechanisms. Phytoremediation technology is a relatively recent technology with research studies conducted mostly during the last four or five decades [24]. Furthermore, fast-growing and high-biomass producing plants such as willow, poplar and Jatropha could be used for both phytoremediation and energy production [25]. Phytoremediation also enjoys popularity with the general public as a ‘’green clean’’ alternative to chemical plants and bulldozers [26],[27].

Quantitative and kinetic studies on phytoremediation are still not much flourished.

2.2 Objectives

1. Study the efficiency of heavy metal sorption of selected plants.
2. Comparative study using different adsorption isotherms.
3. A kinetic study of adsorption.
4. Determination of the bio concentration factor.
5. Determination of the translocation factor.

3 LITERATURE REVIEW

Biological treatment methods exploit natural biological processes that allow certain plants and micro-organisms to help in the remediation of metals in soil and groundwater. Plant based remediation methods for slurries of dredged material and metal contaminated soils had been proposed since the mid-1970s [28].A number of researchers was sceptical about significant metal extraction capability of plants [29]. However, it was reported that a research group in Liverpool, England, making three grasses commercially available for the stabilization of Pb, Cu and Zn wastes. The biological processes for heavy metal remediation of groundwater or sub-surface soil occur through a variety of mechanisms including adsorption, oxidation and reduction reactions and methylation [30].

Potentially useful phytoremediation technologies for remediation of metals-contaminated sites include phytoextraction, phytostabilization and rhizofiltration [31]. A hyper accumulator is defined as a plant with the ability to yield 0.1% Cr, Co, Cu, Ni or 1% Zn, Mn in the above-ground shoots on a dry weight basis [31]. Since metal hyper accumulators generally produce small quantities of biomass, they are not suitable agronomically for phytoremediation. Nevertheless, such plants are valuable stores of genetic and physiologic material and data [28]. In order to provide effective clean up of contaminated soils, it is essential to find, breed, or engineer plants that absorb, translocate and tolerate levels of metals in the 0.1% to1.0% range and are native to the area[30].Wang and Zhao evaluated the feasibility of using biological methods for the remediation of As contaminated soils and groundwater. Baker (1995) observed that some plants such as Urtica, Chenopodium, Thlaspi, Polygonum sachalase and Alyssim possessed the capability of accumulating heavy metals such as Cu, Pb, Cd, Ni and Zn. So these could be considered for indirectly treating contaminated soils. To date, this field of study used to identify the botanical population of contaminated sites and selected some plants for either phytoextraction or phytostabilization purposes. [32]However, more detailed genetic level study must be done to understand the metal uptake capability of plants. Also, Brassica napus (canola) and Raphanus sativus (radish) are shown to be effective in remediating multi-metal contaminated soil.Both willow (Salix sp. 'Tangoio') and poplar (Populus sp. 'Kawa') were shown to uptake B, Cr and Cu from contaminated soils [33]. Recently, review papers focusing on the use of plants and micro-organisms in the site restoration process have been published [34].

From the literature it is clear that certain plants shows specificity in phyto filtration technique. Chinees brake fern was efficient in the uptake of arsenic from ground water .It is reported that at low levels of Se, As enhanced both Se uptake and the translocation of Se from roots to fronds. At higher levels of Se, As suppressed the uptake of Se. These results suggest that As serves to both stimulate and suppress Se uptake in the study of Chinese brake fern (*Pteris vittata* L). The result is also in agreement with the well-known fact that Se is an element with both beneficial and toxic properties. The effect can change from beneficial to toxic based on the concentration of Se in plants[35]. Mercury was more toxic to plants at 5 and 10 mg/L. The plant Indian mustard (*Brassica juncea*) translocated little Hg to the shoots, which accounted for just 0.7–2% of the total Hg in the plants. Most Hg volatilisation occurred from the roots [36]. Duckweed (*Spirodela polyrhiza* L.) not only internalized, but also surface-adsorbed arsenic (mostly arsenate) contributes significantly to the total amount of arsenic uptake in aquatic macrophyte S. *polyrhiza* L. The arsenic uptake in S. *polyrhiza* L. occurred through the phosphate uptake pathway as wellas by physicochemical adsorption on Fe plaques of plant's surfaces[37]. Chilopsis linearis (Cav.) when exposed to both Hg and Au reduced the Hg toxicity. The concentration of Au and Hg in shoots indicated that C. *linearis* absorbed and translocated both Au and Hg at higher concentrations, compared to reported data[38]. Azolla: A. *caroliniana* and A. *filiculoides* are showing a great accumulating capacity to arsenate and arssenite[39]. Phyto filtration studies on *Limnocharis flava* showed greater accumulation of Cd in root than the shoot part[40]. *Plectranthus amboinicus* is tolerant to a wide range of lead concentrations and nutrient deficiency. The plant accumulates considerable amount of lead, particularly in the roots, and translocation to the stem and leaf was limited, indicating that the use of leaves/above-ground parts of the plant for medicinal purposes [41].

4 MATERIALS AND METHODS

We have selected three terrestrial plants *Centella asiatica, Aerva lanata* and *Coleus aromaticus* for the Present study. Among the three *C. asiatica* grows in wet lands. *Aerva lanata*, *C.aromaticus* in moderately wet areas.

4.1 Preparation of the bio sorbent and experimentation

Bio sorbents are prepared by vegetative method. And they are grown in same soil and atmospheric condition and controlled temperature. The plants are grown in the same condition for a period of thirty days. A stock solution of Cd was prepared by dissolving AR grade of $Cd(NO_3)_2$ at an initial concentration of 1mg l−1. The Cd solution of 20 ml is applied to the plants at an interval of two days for a batch of fifteen plants from each variety. One control group of plants was also prepared where Cd treatments were not provided.

Same experimental conditions are applied for repeating the experiment with $Pb(NO_3)_2$.

5 CONCLUSION

Plant samples were separately harvested after 7, 21 and 30 days to analyse for growth rate and metal content. The experiments were set up in triplicate for each condition.

The uptake of heavy metals can be estimated by Atomic Absorption Spectrophotometer by digesting the harvested plant parts in a suitable medium. Medium for digestion is a challenge and trial and error method has conducted for that. By knowing the concentration of heavy metal accumulated in root, shoot and aerial part the bio concentration factor and the translocation factor can be calculated.

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