**INTRODUCTION**

Aquatic plants play important roles in balancing water bodies. They are capable of acquiring large quantities of trace elements and heavy metals. The uptake of trace elements is often increased when aquatic plants are grown in effluent water containing high levels of macronutrients. Heavy metals enter surface and groundwater in various ways and adversely affect flora and fauna have capacity.

Heavy metals are among the contaminants in the environment. Beside the natural activities, almost all human activities also have potential contribution to produce heavy metals as side effects. Migration of these contaminants into no contaminated areas as dust or leachates through the soil and spreading of heavy metals containing sewage sludge are a few examples of events contributing towards contamination of the ecosystems [1].

Several methods are already being used to clean up the environment from these kinds of contaminants, but most of them are costly and far away from their optimum performance. The chemical technologies generate large volumetric sludge and increase the costs [2]; chemical and thermal methods are both technically difficult and expensive that all of these methods can also degrade the valuable component of soils [3]. Conventionally, remediation of heavy-metal-contaminated soils involves either onsite management or excavation and subsequent disposal to a landfill site. This method of disposal solely shifts the contamination problem elsewhere along with the hazards associated with transportation of contaminated soil and migration of contaminants from landfill into an adjacent environment. Soil washing for removing contaminated soil is an alternative way to excavation and disposal to landfill. This method is very costly and produces a residue rich in heavy metals, which will require further treatment. Moreover, these physio-chemical technologies used for soil remediation render the land usage as a medium for plant growth, as they remove all biological activities [4].

Recent concerns regarding the environmental contamination have initiated the development of appropriate technologies to assess the presence and mobility of metals in soil [4], water, and wastewater. Presently, phytoremediation has become an effective and affordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil. Phytoremediation is the use of aquatic plants to clean up a contamination from soils, sediments, and water. This technology is environmental friendly and potentially cost-effective. Aquatic plants with exceptional metal-accumulating capacity are known as hyper accumulator aquatic plants [5]. Phytoremediation takes the advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant degradation abilities of the entire plant body [3].

Many species of aquatic plants have been successful in absorbing contaminants such as lead, cadmium, chromium, arsenic, and various radionuclides from soils. One of phytoremediation categories, phytoextraction, can be used to remove heavy metals from soil using its ability to uptake metals, which are essential for plant growth (Fe, Mn, Zn, Cu, Mg, Mo, and Ni). Some metals with unknown biological function (Cd, Cr, Pb, Co, Ag, Se, Hg) can also be accumulated [5].

The objectives of this paper are to discuss the potential of phytoremediation technique on treating heavy metal-contaminated side, to provide a brief view about heavy metals uptake mechanisms by plant, to give some description about the performance of the aquatic plants to uptake heavy metals and to describe about the fate of heavy metals in plant tissue, especially on arsenic (As), lead (Pb), and mercury (Hg).

Heavy metals, such as arsenic, cadmium, copper, lead and zinc, naturally occur in freshwater environments. These elements enter the water from rocks, soil and other natural sources, or from landfills, mines and other human activity. Aquatic plants such as watercress and pondweeds absorb heavy metals from their environment. Does this Spark an idea?

1. **Heavy Metals: Sources and Effect in the Environment**

Heavy metals are among the most important sorts of contaminant in the environment. Several methods already used to clean up the environment from these kinds of contaminants, but most of them are costly and diﬃcult to get optimum results. Currently, phytoremediation is an eﬀective and aﬀordable technological solution used to extract or remove inactive metals and metal pollutants from contaminated soil and water. This technology is environmental friendly and potentially cost eﬀective. This paper aims to compile some information about heavy metals of arsenic, lead, and mercury (As, Pb, and Hg) sources, eﬀects and their treatment. It also reviews deeply about phytoremediation technology, including the heavy metal uptake mechanisms and several research studies associated about the topics. Additionally, it describes several sources and the eﬀects of As, Pb, and Hg on the environment, the advantages of this kind of technology for reducing them, and also heavy metal uptake mechanisms in phytoremediation technology as well as the factors aﬀecting the uptake mechanisms. Some recommended aquatic plants, which are commonly used in phytoremediation and their capability to reduce the contaminant, are also reported.

 Heavy metals are conventionally defined as elements with metallic properties and an atomic number >20. The most common heavy metal contaminants are Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components in soil [6]. Some of these metals are micronutrients necessary for plant growth, such as Zn, Cu, Mn, Ni, and Co, while others have unknown biological function, such as Cd, Pb, and Hg [1].

Metal pollution has harmful effect on biological systems and does not undergo biodegradation. Toxic heavy metals such as Pb, Co, Cd can be differentiated from other pollutants, since they cannot be biodegraded but can be accumulated in living organisms, thus causing various diseases and disorders even in relatively lower concentrations [7]. Heavy metals, with soil residence times of thousands of years, pose numerous health dangers to higher organisms. They are also known to have effect on plant growth, ground cover and have a negative impact on soil micro flora [8]. It is well known that heavy metals cannot be chemically degraded and need to be physically removed or be transformed into nontoxic compounds [1].

* 1. Arsenic (As)

Arsenic (atomic number 33) is a silver-grey brittle crystalline solid with atomic weight of 74.9, specific gravity 5.73, melting point 817°C (at 28 atm), boiling point 613°C, and vapor pressure 1 mm Hg at 372°C [9]. Arsenic is a semimetallic element with the chemical symbol “As”. Arsenic is odorless and tasteless. Arsenic can combine with other elements to form inorganic and organic arsenicals [10]. In the environment, arsenic is combined with oxygen, chlorine, and sulfur to form inorganic arsenic compounds. Inorganic arsenic compounds are mainly used to preserve wood. Organic arsenic compounds are used as pesticides, primarily on cotton aquatic plants [11].

Arsenic exists in the −3, 0, +3, and +5 valence oxidation states [9], and in a variety of chemical forms in natural waters and sediments [12]. Environmental forms include arsenious acids (H3AsO3, H3AsO3), arsenic acids (H3AsO4), arsenites, arsenates, methylarsenic acid, dimethylarsinic acid, and arsine. Two most common forms in natural waters arsenite and inorganic arsenate, referred as As3+ and As5+ [9]. From both the biological and the toxicological points of view, arsenic compounds can be classified into three major groups. These groups are inorganic arsenic compounds, organic arsenic compounds, and arsine gas [13].

It is a hard acid and preferentially complexes with oxides and nitrogen. Trivalent arsenites predominate in moderately reducing anaerobic environments such as groundwater [9]. The most common trivalent inorganic arsenic compounds are arsenic trioxide, sodium arsenite, and arsenic trichloride [13]. Trivalent (+3) arsenates include As (OH)3, , AsO2OH2−, and [9]. Arsenite (As (OH)3, As3+) is predominant in reduced redox potential conditions [12].

Arsenic is one of the contaminants found in the environment which is notoriously toxic to man and other living organisms [14]. It is a highly toxic element that exists in various species, and the toxicity of arsenic depends on its species. The pH, redox conditions, surrounding mineral composition, and microbial activities affect the form (inorganic or organic) and the oxidation state of arsenic. It is generally accepted that the inorganic species, arsenite [As3+] and arsenate [As5+], are the predominant species in most environments, although the organic ones might also be present [15].

In general, inorganic compounds of arsenic are regarded as more highly toxic than most organic forms, which are less toxic [10, 14, 16, 17]. The trivalent compounds (arsenites) are more toxic than the pentavalent compounds (arsenates) [16, 17]. It has been reported that As3+ is 4 to 10 times more soluble in water than As5+. However, the trivalent methylated arsenic species have been found to be more toxic than inorganic arsenic because they are more efficient at causing DNA breakdown [17]. Although As5+ tends to be less toxic compared to of As3+, it is thermodynamically more stable due to it predominates under normal conditions and becomes the cause of major contaminant in ground water [14]. Arsenate, which is in the pentavalent state (As5+), is also considered toxic and carcinogenic to human [18].

1.2. Lead (Pb)

Lead (Pb), with atomic number 82, atomic weight 207.19, and a specific gravity of 11.34, is a bluish or silvery-grey metal with a melting point of 327.5°C and a boiling point at atmospheric pressure of 1740°C. It has four naturally occurring isotopes with atomic weights 208, 206, 207 and 204 (in decreasing order of abundance). Despite the fact that lead has four electrons on its valence shell, its typical oxidation state is +2 rather than +4, since only two of the four electrons ionize easily. Apart from nitrate, chlorate, and chloride, most of the inorganic salts of lead2+ have poor solubility in water [19]. Lead (Pb) exists in many forms in the natural sources throughout the world and is now one of the most widely and evenly distributed trace metals. Soil and aquatic plants can be contaminated by lead from car exhaust, dust, and gases from various industrial sources.

Pb2+ was found to be acute toxic to human beings when present in high amounts. Since Pb2+ is not biodegradable, once soil has become contaminated, it remains a long-term source of Pb2+ exposure. Metal pollution has a harmful effect on biological systems and does not undergo biodegradation [7].

Soil can be contaminated with Pb from several other sources such as industrial sites, from leaded fuels, old lead plumbing pipes, or even old orchard sites in production where lead arsenate is used. Lead accumulates in the upper 8 inches of the soil and is immobile. Contamination is long-term. Without remedial action, high soil lead levels will never return to normal [20].

In the environment, lead is known to be toxic to aquatic plants, animals, and microorganisms. Effects are generally limited to especially contaminated areas [21]. Pb contamination in the environment exists as an insoluble form, and the toxic metals pose serious human health problem, namely, brain damage and retardation [5].

1.3. Mercury (Hg)

Mercury is a naturally occurring metal that is present in several forms. Metallic mercury is shiny, silver-white, odorless liquid. Mercury combines with other elements, such as chlorine, sulfur, or oxygen, to form inorganic mercury compounds or salts, which are usually white powders or crystals. Mercury also combines with carbon to make organic mercury compounds [22]. Mercury, which has the lowest melting point (−39°C) of all the pure metals, is the only pure metal that is liquid at room temperature. However, due to its several physical and chemical advantages such as its low boiling point (357°C) and easy vaporization, mercury is still an important material in many industrial products [23]. As any other metal, mercury could occur in the soil in various forms. It dissolves as free ion or soluble complex and is nonspecifically adsorbed by binding mainly due to the electrostatic forces, chelated, and precipitated as sulphide, carbonate, hydroxide, and phosphate. There are three soluble forms of Hg in the soil environment. The most reduced is Hg0 metal with the other two forms being ionic of mercurous ion and mercuric ion Hg2+, in oxidizing conditions especially at low pH. Hg+ ion is not stable under environmental conditions since it dismutates into Hg0 and Hg2+. A second potential route for the conversion of mercury in the soil is methylation to methyl or dimethyl mercury by anaerobic bacteria [24].

Mercury is a persistent environmental pollutant with bioaccumulation ability in fish, animals, and human beings [23]. Mercury salts and organomercury compounds are among the most poisonous substances in our environment. The mechanism and extent of toxicity depend strongly on the type of compound and the redox state of mercury [25].

Environmental contamination due to mercury is caused by several industries, petrochemicals, mining, painting, and by agricultural sources such as fertilizer and fungicidal sprays [26]. Some of the more common sources of mercury found throughout the environment include but may not be limited to the household bleach, acid, and caustic chemicals (e.g., battery acid, household lye, muriatic acid (hydrochloric acid), sodium hydroxide, and sulfuric acid), instrumentation containing mercury (e.g., medical instruments, thermometers, barometers, and manometers), dental amalgam (fillings), latex paint (manufactured prior to 1990), batteries, electric lighting (fluorescent lamps, incandescent wire filaments, mercury vapor lamps, ultraviolet lamps), pesticides, pharmaceuticals (e.g., nasal sprays, cosmetics, contact lens products), household detergents and cleaners, laboratory chemicals, inks and paper coatings, lubrication oils, wiring devices and switches, and textiles. Though mercury use in many of the above items being produced now is restricted or banned, there are still some existing, older products in use [22].

Terrestrial aquatic plants are generally insensitive to the harmful effects of mercury compounds; however, mercury is known to affect photosynthesis and oxidative metabolism by interfering with electron transport in chloroplasts and mitochondria. Mercury also inhibits the activity of aquaporin and reduces plant water uptake [17].

Mercury and its compounds are cumulative toxins and in small quantities are hazardous to human health. The major effects of mercury poisoning manifest as neurological and renal disturbances as it can easily pass the blood-brain barrier and has effect on the brain [26].

1. **Phytoremediation Technology**

Phytoremediation techniques have been briefly depicted in many literatures or articles. The generic term “phytoremediation” consists of the Greek prefix phyto (plant), attached to the Latin root remedium (to correct or remove an evil) [18, 19].

Specific plant species can absorb and hyperaccumulate metal contaminants and/or excess nutrients in harvestable root and shoot tissue, from the growth substrate through phytoextraction process. This is for metals, metalloids, radionuclides, nonmetals, and organics contaminants in soils, sediments, and sludges medium [19, 21].

Submerged aquatic plants, such as parrot feather, grow completely below the water surface. Emergent aquatic plants, such as rushes, grow from below the surface and have leaves and stems above the surface. According to an article published in "Chemosphere" in 2002, submerged aquatic plants usually have the highest heavy metal levels.

High heavy metal levels can harm or kill some, but not all, aquatic plant species. For example, copper interferes with photosynthesis and respiration in algae. On the other hand, the 2002 "Chemosphere" article states that some aquatic plants, such as rushes, can tolerate or excrete high levels of heavy metals.

Aquatic plants act as filters and can help to reduce heavy metal levels in water. However, lead and other toxic heavy metals can move through the food chain to humans, cause cancer, and other health problems.

Several researchers have been exploring contaminant uptake by aquatic plants and its mechanisms. It could be used to optimize the factors to improve the performance of plant uptake. According to Sinha et al. [26], the aquatic plants act as both “accumulators” and “excluders”. Accumulators survive despite concentrating contaminants in their aerial tissues. They biodegrade or biotransform the contaminants into inert forms in their tissues. The excluders restrict contaminant uptake into their biomass.

Aquatic plants have evolved highly specific and very efficient mechanisms to obtain essential micronutrients from the environment, even when present at low ppm levels. Plant roots, aided by plant-produced chelating agents and plant-induced pH changes and redox reactions, are able to solubilize and take up micronutrients from very low levels in the soil, even from nearly insoluble precipitates. Aquatic plants have also evolved highly specific mechanisms to translocate and store micronutrients. These same mechanisms are also involved in the uptake, translocation, and storage of toxic elements, whose chemical properties simulate those of essential elements. Thus, micronutrient uptake mechanisms are of great interest to phytoremediation [17].

The range of known transport mechanisms or specialized proteins embedded in the plant cell plasma membrane involved in ion uptake and translocation include (1) proton pumps (″-ATPases that consume energy and generate electrochemical gradients), (2) co- and antitransporters (proteins that use the electrochemical gradients generated by ″-ATPases to drive the active uptake of ions), and (3) channels (proteins that facilitate the transport of ions into the cell). Each transport mechanism is likely to take up a range of ions. A basic problem is the interaction of ionic species during uptake of various heavy metal contaminants. After uptake by roots, translocation into shoots is desirable because the harvest of root biomass is generally not feasible. Little is known regarding the forms in which metal ions are transported from the roots to the shoots [17].

Plant uptake-translocation mechanisms are likely to be closely regulated. Aquatic plants generally do not accumulate trace elements beyond near-term metabolic needs. And these requirements are small ranging from 10 to 15 ppm of most trace elements suffice for most needs [17]. The exceptions are “hyperaccumulator” aquatic plants, which can take up toxic metal ions at levels in the thousands of ppm. Another issue is the form in which toxic metal ions are stored in aquatic plants, particularly in hyperaccumulating aquatic plants, and how these aquatic plants avoid metal toxicity. Multiple mechanisms are involved. Storage in the vacuole appears to be a major one [17].

Water, evaporating from plant leaves, serves as a pump to absorb nutrients and other soil substances into plant roots. This process, termed evapotranspiration, is responsible for moving contamination into the plant shoots as well. Since contamination is translocated from roots to the shoots, which are harvested, contamination is removed while leaving the original soil undisturbed. Some aquatic plants that are used in phytoextraction strategies are termed “hyperaccumulators.” They are aquatic plants that achieve a shoot-to-root metal-concentration ratio greater than one. Nonaccumulating aquatic plants typically have a shoot-to-root ratio considerably less than one. Ideally, hyperaccumulators should thrive in toxic environments, require little maintenance and produce high biomass, although few aquatic plants perfectly fulfill these requirements [18].

Metal accumulating plant species can concentrate heavy metals like Cd, Zn, Co, Mn, Ni, and Pb up to 100 or 1000 times those taken up by nonaccumulator (excluder) aquatic plants. In most cases, microorganism’s bacteria and fungi, living in the rhizosphere closely associated with aquatic plants, may contribute to mobilize metal ions, increasing the bioavailable fraction. Their role in eliminating organic contaminants is even more significant than that in case of inorganic compounds [19, 20].

1. **Effectiveness of Heavy Metals Uptake by Aquatic plants**

Several studies have described the performance of heavy metals uptake by aquatic plants. It is reported that phytoremediation technology is an alternative to treat heavy-metal-contaminated side, which will be more admitted in order to remediate the environment.

Phytoremediation techniques may also be more publicly acceptable, aesthetically pleasing, and less disruptive than the current techniques of physical and chemical process [18]. Advantages of this technology are its effectiveness in contaminant reduction, low-cost, being applicable for wide range of contaminants, and in overall, it is an environmental friendly method.

The major advantages of the heavy metal adsorption technology by biomass are its effectiveness in reducing the concentration of heavy metal ions to very low levels and the use of inexpensive biosorbent materials [2]. Phytoremediation as possibly the cleanest and cheapest technology can be employed in the remediation of selected hazardous sites [19]. Phytoremediation encompasses a number of different methods that can lead to contaminant degradation [24].

Phytoremediation is a low-cost option and inexpensive approach for remediating environmental media, particularly suited to large sites that have relatively low levels of contamination [24]. This technology has been receiving attention lately as an innovative, cost-effective alternative to the more established treatment methods used at hazardous waste sites [19]. Phytoremediation potentially offers unique, low cost solutions to many currently problems of soil contamination [22, 25]. It is inexpensive (60–80% or even less costly) than conventional physicochemical methods, since it does not require expensive equipment or highly specialized personnel. It is cost-effective for large volumes of water having low concentrations of contaminants and for large areas having low to moderately contaminated surface soils [26].

It is applicable to a wide range of toxic metals and radionuclides [12] and useful for treating a broad range of environmental contaminants, including organic and inorganic contaminants [16].

Phytoremediation is regarded as a new approach for the cleanup of contaminated soils, water, and ambient air [34]. Phytoremediation research can also contribute to the improvement of poor soils such as those with high aluminum or salt levels [25]. It is applicable to a range of toxic metals and radionuclides, minimal environmental disturbance, elimination of secondary air or water-borne wastes, and public acceptance [32]. Phytoextraction is considered as an environmentaly friendly method to remove metals from contaminated soils. This method can be used in much larger-scale clean-up operations and has been applied for other heavy metals [26]. It is an esthetically pleasing, solar-energy-driven cleanup technology, there is minimal environmental disruption, and treatment preserves topsoil. The applications decrease the amount of soil disturbance compared to conventional methods. It can be performed with minimal environmental disturbance with topsoil left in a usable condition and may be reclaimed for agricultural use. The organic pollutants may be degraded to CO2 and H2O, removing environmental toxicity [6]. Phytoremediation can be an alternative to the much harsher remediation technologies of incineration, thermal vaporization, solvent washing, or other soil washing techniques, which essentially destroy the biological component of the soil and can drastically alter its chemical and physical characteristics as well as creating a relatively nonviable solid waste. Phytoremediation actually benefits the soil, leaving an improved, functional soil ecosystem at costs estimated at approximately one-tenth of those currently adopted technologies [3]. It is the ecological cleanup technology for contaminated soils and is known as a green technology.

Another advantage of phytoremediation is the generation of a recyclable metal-rich plant residue [2]. Phytoremediation could be a viable option to decontaminate heavy-metal-polluted soils, particularly when the biomass produced during the phytoremediation process could be economically valorized in the form of bioenergy. The use of metal-accumulating bioenergy crops might be suitable for this purpose. If soils, contaminated with heavy metals, are phytoremediated with oil crops, biodiesel production from the resulting plant oil could be a viable option to generate bioenergy [4]. In large-scale applications, the potential energy stored can be utilized to generate thermal energy [6]. The success of the phytoextraction technique depends upon the identification of suitable plant species that can hyperaccumulate heavy metals and produce large amounts of biomass using established crop production and management practices [24].

1. **Limitations of Phytoremediation Technology**

On the other hand, there are certain limitations to phytoremediation system. Among them are being time-consuming method, the amount of produced biomass, the root depth, soil chemistry and the level of contamination, the age of plant, the contaminant concentration, the impacts of contaminated vegetation, and climatic condition.

Phytoremediation can be a time-consuming process, and it may take at least several growing seasons to clean up a site. The intermediates formed from those organic and inorganic contaminants may be cytotoxic to aquatic plants [46]. Phytoremediation is also limited by the growth rate of the aquatic plants. More time may be required to phytoremediate a site as compared with other more traditional cleanup technologies. Excavation and disposal or incineration takes weeks to months to accomplish, while phytoextraction or degradation may need several years. Therefore, for sites that pose acute risks for human and other ecological receptors, phytoremediation may not be the remediation technique of choice [9, 6]. Phytoremediation might be best suited for remote areas where human contact is limited or where soil contamination does not require an immediate response [8].

Under the best climatic conditions, with irrigation and fertilization, total biomass productivities can approach 100 t/ha/y. One of the unresolved issues is the tradeoff between toxic element accumulation and productivity. In practice, a maximum harvestable biomass yield of 10 to 20 t/ha/y would be likely, particularly for heavy metal accumulating aquatic plants. These values for productivity of biomass and heavy metal content would limit annual toxic element removal capacity between about 10 and 400 kg/ha/y, depending on the pollutant, plant species, climatic and other factors. For a target soil depth of 30 cm (4,000 t/ha), this amounts to an annual reduction from 2.5 to 100 ppm in soil toxic element levels. This is often an acceptable rate of contaminant removal, allowing site remediation over a few years to a couple of decades, particularly where the concentration of the contaminant can be lowered sufficiently to meet regulatory criteria. These values for productivity of biomass and heavy metal content would limit annual toxic element removal capacity between 10 and 400 kg/ha/y, depending on the pollutant, plant species, climatic and other factors [17].

The success of phytoremediation may be limited by factors such as growing time, climate, root depth, soil chemistry, and level of contamination [38]. Root contact is a primary limitation on phytoremediation applicability. Remediation with aquatic plants requires that contaminants be in contact with the root zone of the aquatic plants. Either the aquatic plants must be able to extend roots to the contaminants, or the contaminated media must be moved to be within range of the aquatic plants [19]. Restricted to sites with shallow contamination within rooting zone of remediative aquatic plants, ground surface at the site may have to be modified to prevent flooding or erosion [26].

Age greatly affects the physiological activity of a plant, especially its roots. Generally, roots of a young plant display greater ability to absorb ions than do those of an old plant when they are similar in size. It is important to use healthy young aquatic plants for more efficient plant removal. However, this does not rule out the use of larger older aquatic plants whose larger size may compensate for their lower physiological activity as compared to smaller younger aquatic plants [25].

High concentrations of contaminants may inhibit plant growth and, thus, may limit application on some sites or some parts of sites. This phytotoxicity could lead to a remedial approach in which high-concentration waste is handled with expensive ex techniques that quickly reduce acute risk, while phytoremediation is used over a longer period of time to clean the high volumes of lower contaminant concentrations [19]. A major limitation in the phytoremediation of toxic elements is the maximal level that can be accumulated by aquatic plants. Aquatic plants with the highest levels of toxic metal contents, known as “hyperaccumulators”, generally exhibit, on a dry weight basis, from about 2000 ppm (0.2%) for more toxic elements (Cd, Pb) to above 2% for the less toxic ones (Zn, Ni, Cu) [25]. Restricted to sites with low contaminant concentrations, the treatment is generally limited to soils at one meter from the surface and groundwater within a few meters of the surface with soil amendments may be required [6].

Some ecological exposure may occur whenever aquatic plants are used to interact with contaminants from the soil. The fate of the metals in the biomass is a concern. Although some forms of phytoremediation involve accumulation of metals and require handling of plant material embedded with metals, aquatic plants do not accumulate significant levels of organic contaminants. While metal-accumulating aquatic plants will need to be harvested and either recycled or disposed of in compliance with applicable regulations, most phytoremediative aquatic plants do not require further treatment or disposal [9]. Harvested plant biomass from phytoextraction may be classified as a hazardous waste; hence, disposal should be proper. Consumption of contaminated plant biomass is a cause of concern; contaminants may still enter the food chain through animals/insects that eat plant material containing contaminants [16].

Climatic or hydrologic conditions may restrict the rate of growth of aquatic plants that can be utilized. Introduction of nonnative species may affect biodiversity [16].

However, excessive accumulation of these heavy metals can be toxicto most aquatic plants. The ability to both tolerate elevated levels of heavy metals and accumulate them in very high concentrations has been evolved both independently and together in number of different plant species. Eutrophication of a water body signifies the aging of a lake. It is caused by the accumulation of nutrients, sediments, silt and organic matter in the lake from the surrounding watershed.

Macrophytic vegetation plays an important role in maintaining the ecosystem of a lake. Various types of macrophytes emergent, free floating, submerged are generally observed in an aquatic ecosystem. Free-floating macrophytes leaves & roots are not attached in sediments. Aquatic aquatic plants have tremendous capacity of absorbing nutrients and other substances from the water and hence brings down the pollution load. The purpose of the study is to utilize these macrophytes as bio-filters and to observe efficiency of various macrophytes to remove pollutants available in ponds.

Contamination of the aquatic bodies by various pollutants (both synthetics and organic) such as pesticides, Poly Aromatic Hydrocarbons, heavy metals, etc., have caused imbalance in the natural functioning of the ecosystem. Phytoremediation works best at sites with low to medium amount of pollution, and at sites contaminated with metals. With these special characteristics of aquatic plants, these can be employed easily for cost effective and eco-friendly technology in pollution abatement programs.

**CONCLUSION**

Heavy metals uptake, by aquatic plants using phytoremediation technology, seems to be a prosperous way to remediate heavy-metals-contaminated environment. It has some advantages compared with other commonly used conventional technologies. Several factors must be considered in order to accomplish a high performance of remediation result. The most important factor is a suitable plant species, which can be used to uptake the contaminant. Even the phytoremediation technique seems to be one of the best alternative, it also has some limitations. Prolong research needs to be conducted to minimize this limitation in order to apply this technique effectively.

Aquatic plants in a high content of heavy metals, regardless of whether they belong to different ecological groups can store elements in rather high concentrations, but to a certain limit, the excess of which can cause degradation of aquatic plants and their death.

Phytovolatilization process is the aquatic plants ability to absorb and subsequently volatilize the contaminant into the atmosphere. This process is for metal contaminants in groundwater, soils, sediments, and sludges medium. Since phytotransformation/phytodegradation process is the breakdown of contaminants taken up by aquatic plants through metabolic processes within the plant or the breakdown of contaminants externally to the plant through the effect of compounds produced by the aquatic plants. This process is for complex organic molecules that are degraded into simpler molecule contaminants in soils, sediments, sludges, and groundwater medium [19, 21].

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**GLOSSARY**

|  |  |
| --- | --- |
|  | **A** |
| 1 | Abatement снижение  |
| 2 | Abilities возможности |
| 3 | Able способный  |
| 4 | Above вне, за пределами |
| 5 | Absorb поглощать |
| 6 | According to в соответствии с |
| 7 | Acceptance принятие, подтверждение |
| 8 | Accumulate накапливать |
| 9 | Accumulation накопление |
| 10 | Activities деятельность, активность |
| 11 | Adsorption поглощение |
| 12 | Advantage преимущество |
| 13 | Advantage давать преимущество |
| 14 | Adjacent прилегающий |
| 15 | Aerial газообразный |
| 16 | Affordable доступный |
| 17 | Agents агенты |
| 18 | Agricultural сельскохозяйственный |
| 19 | Aided при помощи |
| 20 | Air воздух |
| 21 | Algae морские водоросли |
| 22 | Alternative альтернативный, запасной |
| 23 | Aluminum алюминиевый |
| 24 | Ambient окружающий |
| 25 | Amount количество |
| 26 | Appear появляться |
| 27 | Applied прикладной |
| 28 | Approach подход |
| 29 | Appropriate подходящий |
| 30 | Aquatic plants водные растения |
| 31 | Area территория, площадь |
| 32 | Aromatic ароматический |
| 33 | Arsenic мышьяк |
| 34 | Assess оценивать, определять |
| 35 | Associated связанный |
| 36 | Attention внимание |
| 37 | Avoid избегать |
|  | **B** |
| 38 | Basic основной, главный |
| 39 | Become становиться |
| 40 | Below ниже |
| 41 | Bioaccumulation биоаккумуляция, бионакопление |
| 42 | Biodegrade разложение |
| 43 | Biological биологический |
| 44 | Biomass биомасса |
| 45 | Bio transform био преобразование |
| 46 | Body тело |
| 47 | Brief легкий, короткий |
| 48 | Briefly вкратце |
|  | **C** |
| 49 | Cadmium кадмий |
| 50 | Can консервная банка |
| 51 | Capabilities возможности |
| 52 | Categories категории |
| 53 | Capacity мощность |
| 54 | Cell клетка |
| 55 | Changes изменения |
| 56 | Channels каналы |
| 57 | Chemical химический |
| 58 | Chemosphere хемосфера |
| 59 | Chromium хром |
| 60 | Clean очищать |
| 61 | Compared сравнимый |
| 62 | Component компонент, составляющая |
| 63 | Concentration концентрация, содержание |
| 64 | Condition условие |
| 65 | Considered рассматриваемый |
| 66 | Consist состоять |
| 67 | Containing содержащий |
| 68 | Contaminant загрязняющее вещество |
| 69 | Contamination загрязнение |
| 70 | Contribute вносить вклад |
| 71 | Conventional условный |
| 72 | Costly дорогостоящий |
| 73 | Currently текущий |
|  | **D** |
| 74 | Decrease снижать |
| 75 | Degradation деградация |
| 76 | Degrade деградировать |
| 77 | Degraded деградирующий |
| 78 | Depicted изображенный |
| 79 | Depredate опустошать, разорять |
| 80 | Describe описывать |
| 81 | Description описание |
| 82 | Desirable желаемый |
| 83 | Despite не смотря на |
| 84 | Development развитие |
| 85 | Difficult трудность |
| 86 | Discuss обсуждать |
| 87 | Disposal распоряжение |
| 88 | Disturbance нарушение |
| 89 | Drive вести (к) |
| 90 | During на протяжении |
|  | **E** |
| 91 | Eco эко |
| 92 | Ecosystems экосистемы |
| 93 | Effective эффективный |
| 94 | Elements элементы |
| 95 | Elimination ликвидация, устранение |
| 96 | Emergent срочный, важный |
| 97 | Embedded встроенный |
| 98 | Employed занятый |
| 99 | Encompass охватывать |
| 100 | Enter входить |
| 101 | Entire целый, весь |
| 102 | Environment окружающая среда |
| 103 | Equipment оборудование, приспособление |
| 104 | Essential важный, существенный |
| 105 | Established установленный |
| 106 | Events события |
| 107 | Evolved эволюционирующий |
| 108 | Excavation земляные работы |
| 109 | Exception исключение |
| 110 | Excess лишний, избыточный |
| 111 | Excluder исключать |
| 112 | Excrete выделять |
| 113 | Expensive дорогой |
| 114 | Exploring находящийся в исследовании |
|  | **F** |
| 115 | Factor фактор, показатель |
| 116 | Fate судьба |
| 117 | Feasible осуществимый, возможный |
| 118 | Freshwater пресная вода |
| 119 | Friendly экологически чистый |
| 120 | Function работа |
|  | **G** |
| 121 | Generate создавать |
| 122 | Generic определенный родовыми признаками |
| 123 | Give предоставлять |
| 124 | Grow увеличиваться |
| 125 | Growth рост |
|  | **H** |
| 126 | Harm вред |
| 127 | Harvest урожай |
| 128 | Hazardous опасный |
| 129 | Heavy metals тяжелые металлы |
| 130 | Highest наивысший |
| 131 | Human существо |
| 132 | Hydrocarbons углеводороды |
|  | **I** |
| 133 | Important важный |
| 134 | Improve улучшать |
| 135 | Inactive неактивный |
| 136 | Increase увеличивать |
| 137 | Inert нейтральный |
| 138 | Inexpensive недорогой |
| 139 | Initiated инициирующий |
| 140 | Innovative инновационный |
| 141 | Ion ион |
| 142 | Inorganic неорганический  |
| 143 | Insoluble нерастворимый |
| 144 | Interaction взаимодействие |
| 145 | Interfere вмешиваться |
| 146 | Involve включать в себя |
| 147 | Involved вовлеченный |
| 148 | Issue проблема, вопрос |
|  | **K** |
| 149 | Known известный |
| 150 | Kill уничтожать |
| 151 | Kinds видовое многообразие |
|  | **L** |
| 152 | Landfill свалка |
| 153 | Lead свинец |
| 154 | Lead to вести (к) |
| 155 | Leave оставлять |
| 156 | Level уровень |
| 157 | Low снижение |
|  | **M** |
| 158 | Macrophytic макрофитический |
| 159 | Major основной, главный |
| 160 | Management управление |
| 161 | Materials материалы |
| 162 | Mechanisms механизмы |
| 163 | Media медиа |
| 164 | Membrane мембрана |
| 165 | Mercury ртуть |
| 166 | Metabolic метаболический |
| 167 | Metals металлы |
| 168 | Methods методы |
| 169 | Migration миграция |
| 170 | Minimal минимальный |
| 171 | Mobility подвижность |
| 172 | Multiple многочисленный |
|  | **N** |
| 173 | Naturally естественно |
| 174 | Need нужда |
| 175 | New новый |
| 176 | Number число |
| 177 | Nutrient питательный |
|  | **O** |
| 178 | Objectives предметы исследования |
| 179 | Obtain получать |
| 180 | Occur происходить, появляться |
| 181 | Offer предлагать |
| 182 | Onsite на месте |
| 183 | Optimize оптимизировать |
| 184 | Organic органический |
|  | **P** |
| 185 | Particularly практически |
| 186 | Parrot feather перо попугая |
| 187 | Performed происходящий, осуществляемый |
| 188 | Performance осуществление, выполнение (задачи) |
| 189 | Personnel штат |
| 190 | Phytoextraction фитоэкстракция |
| 191 | Phytoremediation фиторемедиация |
| 192 | Phytoremediative фиторемедиативный |
| 193 | Phytovolatilization фитоволатилизация |
| 194 | Plant растение |
| 195 | Plasma плазма |
| 196 | Pollution загрязнение |
| 197 | Pollutants загрязнители |
| 198 | Poly поли, много- |
| 199 | Pondweeds рдесты |
| 200 | Poor несчастный, пострадавший |
| 201 | Possibly возможно |
| 202 | Potential потенциальный |
| 203 | Potentially потенциально |
| 204 | Precipitate выпадать в осадок |
| 205 | Presence присутствие, наличие |
| 206 | Preserve сохранять |
| 207 | Problem проблема |
| 208 | Process процесс |
| 209 | Properties свойства |
| 210 | Proteins протеины |
| 211 | Proton протон |
| 212 | Provide предоставлять, обеспечивать |
| 213 | Public общественный |
|  | **R** |
| 214 | Radionuclides радионуклиды |
| 215 | Range спектр |
| 216 | Ranging варьирующийся  |
| 217 | Reaction реакция |
| 218 | Recent недавний |
| 219 | Receiving получающий |
| 220 | Reclaimed заявленный снова, восстановленный |
| 221 | Redox окислительно-восстановительный  потенциал |
| 222 | Reduce снижать |
| 223 | Regarded рассматриваемый |
| 224 | Regarding касательно |
| 225 | Regulated регулируемый |
| 226 | Relatively относительно |
| 227 | Remediating устранение последствий |
| 228 | Remediation восстановление |
| 229 | Remove удалять |
| 230 | Removing удаляя |
| 231 | Report сообщать |
| 232 | Requirements требования |
| 233 | Research поиск |
| 234 | Researcher исследователь |
| 235 | Respiration дыхание |
| 236 | Restrict ограничивать |
| 237 | Rocks скалы |
| 238 | Role роль |
| 239 | Roots корень |
| 240 | Rushes камыши |
|  | **S** |
| 241 | Salt соль |
| 242 | Secondary второстепенный |
| 243 | Sediment осадок |
| 244 | Selected отборный |
| 245 | Selective селективный, избирательный |
| 246 | Several несколько |
| 247 | Shifts смены |
| 248 | Side сторона |
| 249 | Sludge ил |
| 250 | Soil почва |
| 251 | Solar-energy-driven управляемый солнечной энергией |
| 252 | Solubilize растворение |
| 253 | Solution решение |
| 254 | Sorts разновидности |
| 255 | Sources источники |
| 256 | Specialized специализированный |
| 257 | Species виды |
| 258 | Specific особый |
| 259 | State состояние |
| 260 | Stem стебель, ствол |
| 261 | Store хранение |
| 262 | Subsequent последующий |
| 263 | Substrate подложка |
| 264 | Successful успешный |
| 265 | Submerged погруженный |
| 266 | Suffice достаточный |
| 267 | Suited подходящий |
| 268 | Surface поверхность |
| 269 | Survive выживать |
|  | **T** |
| 270 | Take брать |
| 271 | Technologies технологии  |
| 272 | Term срок |
| 273 | Thermal термический |
| 274 | Tissue слой, сеть |
| 275 | Tolerate терпимый |
| 276 | Topsoil верхний слой почвы |
| 277 | Toxic токсичный |
| 278 | Trace путь |
| 279 | Translocate смещать, перемещать |
| 280 | Translocation смещение |
| 281 | Transportation перемещение, переход |
| 282 | Treating отношение |
| 283 | Treatment лечение, обработка |
|  | **U** |
| 284 | Unique уникальный |
| 285 | Uptake поглощение |
| 286 | Usable потребляемый |
| 287 | Use потребление |
|  | **V** |
| 288 | Vacuole вакуоль |
| 289 | Valuable ценный |
| 290 | Various разнообразный |
| 291 | Vegetation растительность |
| 292 | View обзор |
| 293 | Volume объем |
| 294 | Volumetric объемный |
|  | **W** |
| 295 | Waste потеря |
| 295 | Water вода |
| 297 | Water surface водная поверхность |
| 298 | Wide распространенный |
|  | **Z** |
| 299 | Zinc цинк |
| 300 | Zonk  | поражать |

**References**

1. A. Gaur and A. Adholeya, “Prospects of arbuscular mycorrhizal fungi in phytoremediation of heavy metal contaminated soils,” Current Science, vol. 86, no. 4, pp. 528–534, 2004.

2. R. Rakhshaee, M. Giahi, and A. Pourahmad, “Studying effect of cell wall's carboxyl-carboxylate ratio change of Lemna minor to remove heavy metals from aqueous solution,” Journal of Hazardous Materials, vol. 163, no. 1, pp. 165–173, 2009. View at Publisher · View at Google Scholar · View at PubMed

3. R. R. Hinchman, M. C. Negri, and E. G. Gatliff, “Phytoremediation: using green aquatic plants to clean up contaminated soil, groundwater, and wastewater,” Argonne National Laboratory Hinchman, Applied Natural Sciences, Inc, 1995, http://www.treemediation.com/Technical/Phytoremediation\_1998.pdf.

4. I. Shtangeeva, J. V.-P. Laiho, H. Kahelin, and G. R. Gobran, “Phytoremediation of metal-contaminated soils. Symposia Papers Presented Before the Division of Environmental Chemistry,” American Chemical Society, Anaheim, Calif, USA, 2004, http://ersdprojects.science.doe.gov/workshop\_pdfs/california\_2004/p050.pdf.

5. K. Cho-Ruk, J. Kurukote, P. Supprung, and S. Vetayasuporn, “Perennial aquatic plants in the phytoremediation of lead-contaminated soils,” Biotechnology, vol. 5, no. 1, pp. 1–4, 2006. View at Publisher · View at Google Scholar

6. M. M. Lasat, “Phytoextraction of metals from contaminated soil: a review of plant/soil/metal interaction and assessment of pertinent agronomic issues,” Journal of Hazardous Substance Research, vol. 2, no. 5, pp. 1–25, 2000.

7. E. Pehlivan, A. M. Özkan, S. Dinç, and S. Parlayici, “Adsorption of Cu2+ and Pb2+ ion on dolomite powder,” Journal of Hazardous Materials, vol. 167, no. 1–3, pp. 1044–1049, 2009. View at Publisher · View at Google Scholar · View at PubMed

8. S. Roy, S. Labelle, P. Mehta et al., “Phytoremediation of heavy metal and PAH-contaminated brownfield sites,” Plant and Soil, vol. 272, no. 1-2, pp. 277–290, 2005. View at Publisher · View at Google Scholar

9. D. Mohan and C. U. Pittman Jr., “Arsenic removal from water/wastewater using adsorbents—a critical review,” Journal of Hazardous Materials, vol. 142, no. 1-2, pp. 1–53, 2007. View at Publisher · View at Google Scholar · View at PubMed

10. National Ground Water Association, Copyright 2001. What you need to know.

 11. U.S. Department of Health and Human Services, Public Health Service Agency for Toxic Substances and Disease Registry. Division of Toxicology and Environmental Medicine. Arsenic. 2005, http://www.baltimorehealth.org/info/ATSDR%20fact%20sheet.pdf.

12. H. Hasegawa, M. A. Rahman, T. Matsuda, T. Kitahara, T. Maki, and K. Ueda, “Effect of eutrophication on the distribution of arsenic species in eutrophic and mesotrophic lakes,” Science of the Total Environment, vol. 407, no. 4, pp. 1418–1425, 2009. View at Publisher · View at Google Scholar · View at PubMed

 13. WHO Regional Office for Europe, Air Quality Guidelines, chapter 6.1, Arsenic, Copenhagen, Denmark, 2nd edition, 2000, http://www.euro.who.int/document/aiq/6\_1\_arsenic.pdf.

14. P. Chutia, S. Kato, T. Kojima, and S. Satokawa, “Arsenic adsorption from aqueous solution on synthetic zeolites,” Journal of Hazardous Materials, vol. 162, no. 1, pp. 440–447, 2009. View at Publisher · View at Google Scholar · View at PubMed

15. H. A. Andrianisa, A. Ito, A. Sasaki, J. Aizawa, and T. Umita, “Biotransformation of arsenic species by activated sludge and removal of bio-oxidised arsenate from wastewater by coagulation with ferric chloride,” Water Research, vol. 42, no. 19, pp. 4809–4817, 2008. View at Publisher · View at Google Scholar · View at PubMed

16. R. J. Ampiah-Bonney, J. F. Tyson, and G. R. Lanza, “Phytoextraction of arsenic from soil by Leersia oryzoides,” International Journal of Phytoremediation, vol. 9, no. 1, pp. 31–40, 2007. View at Publisher · View at Google Scholar · View at PubMed

17. M. Vaclavikova, G. P. Gallios, S. Hredzak, and S. Jakabsky, “Removal of arsenic from water streams: an overview of available techniques,” Clean Technologies and Environmental Policy, vol. 10, no. 1, pp. 89–95, 2008. View at Publisher · View at Google Scholar

18. A. M. Yusof and N. A. N. N. Malek, “Removal of Cr(VI) and As(V) from aqueous solutions by HDTMA-modified zeolite Y,” Journal of Hazardous Materials, vol. 162, no. 2-3, pp. 1019–1024, 2009. View at Publisher · View at Google Scholar · View at PubMed

19. WHO Regional Office for Europe, Air Quality Guidelines, chapter 6.7, Lead, Copenhagen, Denmark, 2nd edition, 2001, http://www.euro.who.int/document/aiq/6\_7lead.pdf.

20. J. H. Traunfeld and D. L. Clement, “Lead in Garden Soils. Home and Garden,” Maryland Cooperative Extention, University of Maryland, 2001, http://www.hgic.umd.edu/\_media/documents/hg18.pdf.

21. European Commission DG ENV. E3. Heavy Metals in Waste, Final Report Project ENV.E.3/ETU/2000/0058, 2002http://ec.europa.eu/environment/waste/studies/pdf/heavy\_metalsreport.pdf.

22. J. F. Musselman and QEP, “Sources of Mercury in Wastewater, Pretreatment corner,” http://www.cet-inc.com/cmsdocuments//7%20-%20Sources%20of%20Mercury%20in%20Wastewater%20(0204).pdf.

23. T. C. Chang, S. J. You, B. S. Yu, C. M. Chen, and Y. C. Chiu, “Treating high-mercury-containing lamps using full-scale thermal desorption technology,” Journal of Hazardous Materials, vol. 162, no. 2-3, pp. 967–972, 2009. View at Publisher · View at Google Scholar · View at PubMed

24. L. Rodriguez, F. J. Lopez-Bellido, A. Carnicer, F. Recreo, A. Tallos, and J. M. Monteagudo, “Mercury recovery from soils by phytoremediation,” in Book of Environmental Chemistry, pp. 197–204, Springer, Berlin, Germany, 2005.

25. Washington State Lake Whatcom Management Program: Metals

26. Washington State Department of Ecology: The Uses and Benefits of Aquatic Aquatic plants .