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ABSTRACT

Purpose: The study investigated on heavy metals

Methodology: The study used desktop study research design.

Results: Phytoremediation has been perceived to be a more environmentally-friendly "green" and low tech alternative to more active and intrusive remedial methods.

Unique contribution to theory, practice and policy: The potential role of both free living and symbiotic soil microbes in the rhizosphere of plants growing in metal-contaminated soils in enhancing the phytoremediation process can be an important tool to support the technology. The outcome of undergoing genetic engineering investigation concerning plants applicable in phytoremediation may also lead to a better understanding of metal metabolism in plants, which can result in important contributions for the implementation of phytoremediation as a feasible soil remediation technology.

INTRODUCTION

The term "heavy metals" refers to any metallic element that has a relatively high density and is toxic even at low concentration (Lenntech, 2004). Heavy metals is a common term, used for the group of metals and metalloids with atomic density greater than 4 g/cm^3 , or 5 times or more, greater than water (Huton & Symon, 1986). Heavy metals are also defined as elements with metallic properties and an atomic number >20. The most common heavy metal are As, Cd, Cr, Cu, Hg, Pb, and Zn. Metals are natural components occurring in earth. Basing on their role on physiological activities, they can be divided in two groups Essential heavy metals (Fe, Mn, Cu, Zn, & Ni) and Non-essential metals (Cd, Pb, As, Hg & Cr). Essential heavy metals are micronutrients necessary for vital physiological and biochemical functions of plant growth (Ahmadi et al., 2013). They are constituents of many enzymes and proteins and all plants have the ability to accumulate them from soil solution (McCutcheon & Schnoor, 2003) non-essential heavy metals have unknown biological or physiological function as a result are non-essential for plant growth (Raskin et al, 1994).

Metal pollutants have injurious effect on biological systems and do not undergo biodegradation. Toxic heavy metals such as Pb, Co, Cd are different from other pollutants, as they are not biodegradable can be accumulated in living organisms, as a result cause various diseases and disorders even in relatively lower concentrations. They have also effect on plant growth, soil micro-flora (Roy et al., 2005).

Excess level of heavy metals are exposed into environment by industrial waste and fertilizers causes serious concern in nature as they are non- biodegradable and accumulate at high levels. Heavy metals such as Pb, Zn, Cd, As etc. are one of the most toxic pollutants which show hazardous effects on all living livings. It is acknowledged that heavy metals cannot be chemically degraded and need to be physically removed or be transformed into nontoxic compounds (Gaur & Adholeya, 2004).

Most of the soil contaminants can be removed by many other physical methods but the heavy metal pollution of vast cultivated land areas are a serious threat to the agricultural biology. Heavy metals are known to cause toxicities around the world. There are documented cases of many different metals causing toxicity issues. The world's most polluted places threaten the health of more than 10 million people in many countries. According to report, the Chinese city of Linfen, located in the heart of the country's coal region is as an example of the severe pollution faced by many Chinese cities. Haina, Dominican Republic, is the site of a former automobile battery recycling smelter where residents suffer from widespread lead poisoning. The Indian city of Ranipet, where some 3.5 million people are affected by tannery waste, contains hexavalent chromium and azodyes. Mailuu-Suu, Kyrgyzstan, home to a former Soviet uranium plant and severely contaminated with radioactive uranium mine wastes. The Russian industrial city of Norilsk, which houses the world's largest heavy metals smelting complex is where more than 4 million tons of cadmium, copper, lead, nickel, arsenic, selenium and zinc emissions are released annually, the Russian Far East towns of Dalnegorsk and Rudnaya Pristan,residents suffer from serious lead poisoning from an old smelter and the unsafe transport of lead concentrate from the local lead mining site; and in the city of Kabwe, Zambia, mining and smelting operations have led to widespread lead and cadmium contamination. Tannery runoff in India is polluting the water supply of some 3.5 million people (Raskin et al., 1997).

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 (Rakhshaee et al., 2009). Chemical and thermal methods are both technically difficult and expensive that all of these methods can also degrade the valuable component of soils (Hinchman et al., 1995). 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 physico-chemical technologies used for soil remediation render the land usage as a medium for plant growth, as they remove all biological activities.

METAL TOXICITY

All plants have the ability to accumulate essential metals (Ca, Co, Cu, Fe, K, Mg, Mn, Mo, Na, Ni, Se, V & Zn) from the soil solution. Plants need different concentrations for growth and development. This ability also allows plants to accumulate other non-essential metals (Al, As, Au, Cd, Cr, Hg, Pb, Pd, Pt, Sb, Te, Tl & U) which have no known biological function. Moreover, metals cannot be broken down and when concentrations inside the plant cells accumulate above threshold or optimal levels, it can cause direct toxicity by damaging cell structure and inhibit a number of cytoplasmic enzymes (Assche & Clijsters, 1990). In addition, it can cause indirect toxic effects by replacing essential nutrients at cation exchange sites in plants (Taiz & Zeiger, 2002). Schmidt (2003) reported that elevated heavy metal concentrations in the soil can lead to enhanced crop uptake and negative effect on plant growth. At higher concentrations, they interfere with metabolic processes and inhibit growth, sometimes leading to plant death (Schaller & Diez, 1991). Excessive metals in human nutrition can be toxic and can cause acute and chronic diseases (Schmidt, 2003). Zn is an essential trace nutrient to all high plants and animals. Zinc is required in a large number of enzymes and plays an essential role in DNA transcription. Zinc toxicity often leads to leaf chlorosis (Cobbett & Goldsbrough, 2002). Cu is essential micronutrient for plants, but it can be toxic at higher concentrations. Copper (Cu) contributes to several physiological processes in plants including photosynthesis, respiration, carbohydrate distribution, nitrogen and cell wall metabolism, seed production including also disease resistance (Kabata-Pendias & Pendias, 2001). The higher concentration of Cu may account for the suppressed root growth, leaf chlorosis observed among plants (Baker and Walker, 1989). Kuzovkina et al., (2004) mentioned that cadmium is not an essential element for plant metabolism and can be strongly phytotoxic, causing rapid death. It is known to disturb enzyme activities, to inhibit the DNA-mediated transformation in microorganisms, to interfere in the symbiosis between microbes and plants, as well as to increase plant predisposition to fungal invasion (Kabata-Pendias & Pendias, 2001). Khan and Moheman (2006) reported that Ni is considered to be among non essential element needed for the healthy growth of plants, animals and soil microbes. However, the recent literature survey available is suggesting that nickel is an essential element in many species of plants and animals. It interacts with iron found in haemoglobin and helps in oxygen transport, stimulate the metabolism as well as being regarded as a key metal in several plants and animals enzymes systems. Ni is readily transported from roots to over ground plant tissues. However at higher concentrations it can be toxic. Pb is a nonessential element in metabolic processes and may become toxic or lethal to many organisms even when absorbed in small amounts.

SOURCES OF METAL POLLUTION

Generally Geological and anthropogenic activities are the sources of heavy metal contamination (Dembitsky, 2003). Sources of anthropogenic metal contamination include industrial effluents, fuel production, mining, smelting processes, military operations, utilization of agricultural chemicals, small-scale industries (including battery production, metal products, metal smelting and cable coating industries), brick kilns and coal combustion (Zhen-Guo et al., 2002). One of the prominent sources contributing to increased load of soil contamination is disposal of municipal wastage. These wastes are either dumped on roadsides or used as land fills, while sewage is used for irrigation. These wastes, although useful as a source of nutrients, are also sources of carcinogens and toxic metals. Other sources can include unsafe or excess application of (sometimes banned) pesticides, fungicides and fertilizers (Zhen-Guo et al., 2002). Additional potential sources of heavy metals include irrigation water contaminated by sewage and industrial effluent leading to contaminated soils and vegetables (Bridge, 2004).

Agricultural activities in urban areas and at the periphery of industrial units are under scanner due to potential threat of metal pollution through sewage effluents and sludge coming out as waste from such units leading to their subsequent entry to the food chain through various crops (primarily vegetables) that are grown on fields with these wastes (Ikhuoria & Okieimen 2000). Further, the long term applications of sewage effluents and sludge have also been reported to increase the concentrations of trace metals significantly in large areas under peri-urban agriculture (Manhor, 2006).

Heavy metal pollution is a global problem, although severity and levels of pollution differ from place to place. At least 20 metals are classified as toxic with half of them emitted into the environment that poses great risks to human health. The economic, agricultural and industrial developments that are often linked to polluting the environment. Since the beginning of the industrial revolution, soil pollution by toxic metals has accelerated dramatically. About 90% of the anthropogenic emissions of heavy metals have occurred since 1900, it is now well recognized that human activities lead to a substantial accumulation of heavy metals in soils on a global scale. Man’s exposure to heavy metals comes from industrial activities like mining, smelting, refining and manufacturing processes.

A number of chemicals, heavy metals and other industries in the coastal areas have resulted in significant discharge of industrial effluents into the coastal water bodies. These toxic substances are released into the environment and contribute to a variety of toxic effects on living organisms by food chain (Dembitsky, 2003). Heavy metals, such as cadmium, copper, lead; chromium, zinc, and nickel are important environmental pollutants, particularly in areas with high anthropogenic pressure. According to their chemical properties and biological function, heavy metals form a heterogeneous group; toxicity varies by metals and concentrations. Many of them (Hg, Cd, Ni,Pb, Cu, Zn, Cr & Co) are highly toxic both in elemental and soluble salt forms.

Their presence in the atmosphere, soil and water, even in traces can cause serious problems to organisms. Heavy metals bioaccumulation in the food chain especially can be highly dangerous to human health. The most common route of human exposure to heavy metals is through ingestion from both food and water sources (Pickering & Owen, 1997).

Human evolution has led to immense scientific and technological progress. Global development, however, raises new challenges, especially in the field of environmental protection and conservation. Nearly every government around the world advocates for an environment free from harmful contamination for their citizens. However, the demand for a country's economic, agricultural and industrial development outweighs the demand for a safe, pure, and natural environmental. Ironically, it is the economic, agricultural and industrial developments that are often linked to polluting the environment (Mwegoha, 2008). There are conventionally physicochemical soil remediation engineering techniques such as soil washing, incineration, solidification, vapor extraction, thermal desorption, and disposal as waste, anyway, these methods usually cause secondary air or groundwater pollution, and/or destroy the plant productive properties of soils. Moreover, they are usually extremely high in cost, limiting their extensive application particularly in developing countries and for remediation of agricultural soils (Oh et al, 2013).

REMEDIATION MEASURES

Conventional technologies involve the removal of metals from polluted soils by transportation to laboratories, soil washing with chemicals to remove metals, and finally replacing the soil at its original location or disposing of it as hazardous waste (Francis et al., 1999). This remediation strategy is an ex situ approach and can be very expensive and damaging to the soil structure and ecology (Salt et al., 1995). Immobilization of heavy metals through the addition of lime, phosphate and calcium carbonate ($CaCO3$) (Chen et al., 2000) have been suggested as remediation techniques. These remediation technologies have the advantage of immediately dropping the risk factors arising from metal contamination. Many remediation technologies have been developed to treat soil, leachate, wastewater, and ground-water contaminated by various pollutants including in situ and ex situ methods (Aboulroos et al., 2006). A particular contaminated site may require a combination of procedures to allow the optimum remediation for the prevailing conditions. Biological, physical, and chemical technologies may be used in conjunction with one another to reduce the contamination to a safe and acceptable level. Conventional methods to remediate metal-contaminated soils (soil flushing, solidification/stabilization, vitrification, thermal desorption, encapsulation) (Bio-Wise, 2003) can be used at highly contaminated sites but are not applicable to large areas. These remediation methods require high energy input and expensive machinery (Schnoor, 1997). At the same time they destroy soil structure and decrease soil productivity (Leumann et al., 1995). Phytoremediation has been increasingly received attentions over the recent decades, as an emerging and eco-friendly approach that utilizes the natural properties of plants to remediate contaminated soils (Wang et al, 2003). By growing plants in the contaminated sites, contaminants in soils will be removed, immobilized, or degraded, and the cost is much less expensive than other traditional methods.

PHYTOREMEDIATION

Phytoremediation comes from Ancient Greek word (phyto), meaning "plant", and Latin (remedium), meaning "restoring balance") describes the treatment of environmental problems (bioremediation) through the use of plants that mitigate the environmental problem without the need to excavate the contaminant material and dispose of it elsewhere. Phytoremediation is an emerging technology that uses various plants to degrade, extract, contain, or immobilize contaminants from soil and water. This technology has been receiving attention lately as an innovative, cost-effective alternative to the more established treatment methods used at hazardous waste sites.

Phytoremediation has been applied to a number of contaminants in small-scale field and/or laboratory studies. These contaminants include heavy metals, radionuclides, chlorinated solvents, petroleum hydrocarbons, PCBs, PAHs, organophosphate insecticides, explosives, and surfactants (Khan et al., 2004). Certain species of higher plants can accumulate very high concentrations of metals in their tissues without-showing toxicity (Klassen et al., 2000). Such plants can be used successfully to clean up heavy metal polluted soils if their biomass and metal content are large enough to complete remediation within a reasonable period. For this clean-up method to be feasible, the plants must (1) extract large concentrations of heavy metals into their roots, (2) translocate the heavy metal into the surface biomass, and (3) produce a large quantity of plant biomass. In addition, remediative plants must have mechanisms to detoxify and/or tolerate high metal concentrations accumulated in their shoots. In the natural setting, certain plants have been identified which have the potential to uptake heavy metals. At least 45 families have been identified to hyperaccumulate heavy metal, some of the families are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae and Scrophulariaceae. Brassica juncea, commonly called Indian mustard, has been found to have a good ability to transport lead from the roots to the shoots (United States Protection Agency, 2000). Aquatic plants such as the floating Eichhornia crassipes (water hyacinth), Lemna minor (duckweed), and Pistia have been investigated for use in rhizofiltration (Karkhanis et al., 2005).

1. PROCESS OF PHYTOREMEDIATION

Mechanism of phytoremediation technologies are as given below

1.1.Phytoextraction

It is the best approach to remove the contamination primarily from soil and isolate it, without destroying the soil structure and fertility. It is also referred as phytoaccumulation United States Protection Agency Reports (2000). Phytoextration is the process of absorbtion, concentration and precipitation toxic metals from contaminated soils into the biomass, it is best suited for the remediation of diffusely polluted areas, where pollutants occur only at relatively low concentration and superficially. Several approaches have been used but the two basic strategies of phytoextraction, which have finally developed are; i) Chelate assisted phytoextraction or induced phytoextraction, in which artificial chelates are added to increase the mobility and uptake of metal contaminant. ii) Continuous phytoextraction in this the removal of metal depends on the natural ability of the plant to remediate; only the number of plant growth repetitions are controlled (Salt et al., 1995). The plants may then need to be harvested and

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removed from the site. Even if the harvested plants must be land filled, the mass disposed of is much smaller than the original mass of contaminated soil. Phytoextraction is the uptake/absorption and translocation of contaminants by plant roots into the above ground portions of the plants (shoots) that can be harvested and burned gaining energy and recycling the metal from the ash (Banuelos, 2000).

Taking into account the features of the uptake and translocation mechanisms the ideal plant to be used in phytoextraction should have the following characteristics

- be tolerant to high levels of the metal;
- have a profuse root system;
- have a rapid growth rate;
- have the potential to produce a high biomass in the field; and
- Accumulate high levels of the metal in the harvestable parts, as generally the harvestable portion of most plants is limited to the aboveground parts.

Phytovolatilization

Phytovolatilization is the use of plants to take up contaminants from the soil, transforming them into volatile form and transpiring them into the atmosphere. Some of these contaminants can pass through the plants to the leaves and volatilise into the atmosphere at comparatively low concentrations (Mueller et al., 1999). Phytovolatilization has been mostly used for the removal of mercury, the mercuric ion is transformed into less toxic elemental mercury. The disadvantage is, mercury released into the atmosphere is likely to be recycled by precipitation and then redeposit back into ecosystem. Gary Banuelos of USDS's Agricultural Research Service have found that some plants grow in high Selenium media produce volatile selenium in the form of dimethylselenide and dimethyldiselenide. Phytovolatilization also involves contaminants being taken up into the body of the plant, but then the contaminant, a volatile form thereof, or a volatile degradation product is transpired with water vapor from leaves. Phytovolatilization is the uptake and transpiration of a contaminant by a plant, with release of the contaminant or a modified form of the contaminant to the atmosphere from the plant.

Phytostabilization

Phytostabilization, also referred to as in-place inactivation, is mainly used for the remediation of soil, sediment, and sludges (United States Protection Agency, 2000). It is the use of plant roots to limit contaminant mobility and bioavailability in the soil.

Its main purpose is to (1) decrease the amount of water percolating through the soil matrix, which may result in the formation of a hazardous leachate, (2) act as a barrier to prevent direct contact with the contaminated soil and (3) prevent soil erosion and the distribution of the toxic metal to other areas (Raskin & Ensley, 2000).

Phytostabilization can occur through the sorption, precipitation, complexation, or metal valence reduction. It is useful for the treatment of lead (Pb) as well as arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Some of the advantages associated with this technology are that the disposal of hazardous material/biomass is not required (United States Protection Agency, 2000) and it is very effective when rapid immobilization is needed to preserve ground and surface waters. The presence of plants also reduces soil erosion and decreases the amount of water available in the system (United States Protection Agency, 2000). Phytostabilization has been used to treat contaminated land areas affected by mining activities and Superfund sites. Jadia and Fulekar (2008) reported that in a greenhouse, sorghum (fibrous root grass) remediate soil contaminated by heavy metals and the developed vermicompost was amended in contaminated soil as a natural fertilizer. They reported that growth was adversely affected by heavy metals at the higher concentration of 40 and 50 ppm, while lower concentrations (5 to 20 ppm) stimulated shoot growth and increased plant biomass. Further, heavy metals were efficiently taken up mainly by roots of sorghum plant at all the evaluated concentrations of 5, 10, 20, 40 and 50 ppm.

Rhizofiltration

Rhizofiltration is primarily used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations. Rhizofiltration is the adsorption or precipitation onto plant roots or absorption into the roots of contaminants that are in solution surrounding the root zone by constructed wetland for cleaning up communal wastewater (Kokyo et al., 2014). It is defined as the use of plants, both terrestrial and aquatic, to absorb, concentrate and contaminants from polluted aqueous sources in their roots. Terrestrial plants are more preferred because they have a fibrous and much longer root system, increasing amount of root area that effectively removed the potentially toxic metals.

Phytodegradation

In phytoremediation of organics, plant metabolism contributes to the contaminant reduction by transformation, break down, stabilisation or volatilising contaminant compounds from soil and groundwater. Phytodegradation is the breakdown of organics, taken up by the plant to simpler molecules that are incorporated into the plant tissues (Chaudhry, 1998). Plants contain enzymes that can breakdown and convert ammunition wastes, chlorinated solvents such as trichloroethylene and other herbicides. The enzymes are usually dehalogenases, oxygenases and reductases (Black, 1995).

GENETIC ENGINEERING TO IMPROVE PHYTOREMEDIATION

Plants having superior phytoremediation potential with high biomass production can be an alternative to improve phytoremediation. General plant productivity is controlled by many genes and difficult to promote by single gene insertion. Genetic engineering techniques to implant more efficient accumulator gene into other plants have been suggested by many authors (Brown et al., 1995). Implanting more efficient accumulator genes into other plants that are taller than natural plants increases the final biomass. Zhu et al., (1999) genetically engineered Brassica juncea to investigate rate-limiting factors for glutathione and phytochelatin production; they introduced the Escherichia coli –gshl- gene. The γ-ECS transgenic seedlings showed increased tolerance to cadmium and had higher concentrations of Phytochelatins, γ-GluCys, glutathione, and total nonprotein thiols compared to wild type seedlings. The potential of success of genetic engineering can be limited because of anatomical constraints (Ow, 1996).

ADVANTAGES OF PHYTOREMEDIATION

- phytoremediation includes both variety of organic and inorganic compounds.

- Phytoremediation can be used either as an *in situ* or *ex situ* application. *In situ* applications are frequently considered because minimizes disturbance of the soil and surrounding environment and reduce the spread of contamination via air and waterborne wastes.
- Another advantage of phytoremediation is that it is a green technology and when properly implemented is both environment friendly and aesthetically pleasing to the public.
- Phytoremediation does not require expensive equipment or highly-specialized personnel, and it is relatively easy to implement.
- It is capable of permanently treating a wide range of contaminants in a wide range of environments. However, the greatest advantage of phytoremediation is its low cost compared to conventional clean-up technologies.

LIMITATIONS OF PHYTOREMEDIATION

In contrast to its many positive aspects, phytoremediation does have a few disadvantages and limitations.

- It is restricted to the rooting depth of remediative plants. Remediation with plants is a lengthy process, thus it may take several years or longer to clean up a hazardous waste site, and the contamination may still not be fully remediated.
- The use of invasive, non native species can affect biodiversity.
- The consumption of heavy metal contaminated plants by wildlife is also of concern.
- Unfavorable climate is another important consideration because it can limit plant growth and phytomass production, thus decreasing process efficiency.

UTILIZATION OF PHYTOREMEDIATION BY-PRODUCT

Phytoextraction involves repeated cropping of plants in contaminated soil, until the metal concentration drops to acceptable level. The ability of the plants to account for the decrease in soil metal concentrations as a function of metal uptake and biomass production plays an important role in achieving regulatory acceptance. Metal removal can be accounted by determining metal concentration in plant, multiplied by the biomass produced; and comparing this with the reduction in soil metal concentrations. One of the obstacles for commercial implementation of phytoextraction has been the disposal of contaminated plant material. After each cropping, the plant is removed from the site; this leads to accumulation of huge quantity of hazardous biomass. This hazardous biomass should be stored or disposed appropriately so that it does not pose any risk to the environment. Biomass contains carbon, hydrogen and oxygen, it is known as oxygenated hydrocarbons. Handling of huge quantity of this type of waste is a problem and hence need volume reduction. Composting and compaction has been proposed as post harvest biomass treatment by some authors. Combustion and gasification are the most important sub routes for organized generation of electrical and thermal energy. Recovery of this energy from biomass by burning or gasification could help make phytoextraction more cost-effective. Thermochemical energy conversion best suits the phytoextraction biomass residue because it cannot be utilized in any other way as fodder and fertilizers. Combustion is a crude method of burning the biomass. Bridgewater et al., (1999) reported that pyrolysis is a novel method of municipal waste treatment that might also be used for contaminated plant material. Pyrolysis decomposes material under anaerobic conditions; there is no emission to the air. The final products are pyrolytic fluid oil and coke; heavy metals will remain in the coke, which could be used in smelter.

CONCLUSION

Phytoremediation is emerging as a bio-based and low-cost alternative in the cleanup of heavy metal-contaminated soils. The application of a vegetation cover can limit the local effects and the spreading of the contamination, or even remove via phytoextraction or phytovolatilization the metals from the polluted soil. The future of this technique is still mainly in the research phase, and the optimization and greater understanding of the process by which plants absorb, translocate, and metabolize heavy metals needs to be addressed. There is still much fundamental and applied and field research needed. The potential role of both free living and symbiotic soil microbes in the rhizosphere of plants growing in metal-contaminated soils in enhancing the phytoremediation process can be an important tool to support the technology. The outcome of undergoing genetic engineering investigation concerning plants applicable in phytoremediation may also lead to a better understanding of metal metabolism in plants, which can result in important contributions for the implementation of phytoremediation as a feasible soil remediation technology. A multidisciplinary research effort that integrates the work of plant biologist, soil chemists, microbiologists, geneticists, and environmental engineers thus seems essential for the success of phytoremediation as a soil cleanup technology.

Phytoremediation have many advantageous features that make it an appropriate and successful technology, giving practitioners a valuable option for remediation. These features make it to become the environmentally friendly method of choice because it is nonpolluting, low cost, does not require soil excavation, and is more acceptable to the public than chemical methods. As phytoremediation need a long period, it has not been fully utilized. Further promotion to the practical application of phytoremediation to removal of contaminated soil needs to establish more effective ways for profitable phytoremediation systems. The use of economic plants such as biofuel crops for utilization and remediation of the contaminated sites would be a reasonable choice, as they can both remediate contaminated soils and produce valuable biomass, which could bring income for the owner of the contaminated site.

Phytoremediation is a potential remediation strategy that can be used to decontaminate soils contaminated with inorganic pollutants. Research related to this relatively new technology needs to be promoted and emphasized and expanded in developing countries since it is low cost. In situ, solar driven technology makes use of vascular plants to accumulate and translocate metals from roots to shoots. Harvesting the plant shoots can permanently remove these contaminants from the soil. Phytoremediation does not have the destructive impact on soil fertility and structure that some more vigorous conventional technologies have such as acid extraction and soil washing. This technology can be applied “in situ” to remediate shallow soil, ground water and surface water bodies. Also, phytoremediation has been perceived to be a more environmentally-friendly “green” and low tech alternative to more active and intrusive remedial methods.

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