

# Status of Phytoremediation in World Scenario

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**Abstract** The burning issue of today's environment problem is the release of toxic contaminants from various man made sources resulting in contamination of natural resources of earth and leading to scarcity of clean water and loss of soil fertility. To overcome these drawbacks, the concept of using plant to clean up contaminated environment is not new. about 300 years ago, plants were proposed for use in the treatment of waste water. Land and water pollution by heavy metals is a world wide issue. therefore has been an increasing concern with regard to accumulation of heavy metals in environment as they pose big threat to both human health and natural environment. In central and eastern European countries about 1.7 million sites were contaminated with heavy metals and need reclamation. In developing countries particularly India, China, Pakistan, Bangladesh, soil and water pollution is also severe where small industrial units are pouring their untreated effluents over near agricultural fields. The use of plants species for cleaning polluted soils and water named as phytoremediation has gained increasing attention since last decade, as an emerging cheaper technology. This article reviewed the status of phytoremediation in global prospects.

**Keywords:** contaminated, heavy metals, pollution

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## 1. Introduction

The planet 'Earth' is endowed with rich wealth of natural resources such as forests, wildlife, land, soil, air, water, plants and animals. The race begins when humans started living a stable life rather than a nomadic life. Since the advent of civilization the use and overuse, but now the misuse has led to depletion of various natural resources and today half of our natural wealth are either depleted or at the edge of depletion [1]. In early times, it was believed that our land and its resources are in abundance and will remain available for decades. However, today existing state of our resources shows carelessness and negligence in using them. There are various examples which indicate the exploitation of natural resources by the use of chemical fertilizers in agriculture, release of industrial waste, anthropogenic activities etc. The use of chemical fertilizers, pesticides and herbicides in agriculture has improved the crop yield and productivity but led to the addition of detrimental amount of nitrogen and phosphorus in soil and terrestrial ecosystem. Similarly, the release of toxic contaminants from various man made sources resulted in contamination of natural resources leading to scarcity of clean water and loss of soil fertility [2,3]. The industrial and anthropogenic activities had also led to the contamination of agricultural lands resulting in loss of biodiversity. The biodiversity of plant and animal species play important role in the development of healthy and productive ecosystem and, thus play a major role of economic benefits to man and environment. Unfortunately,

rapidly growing population and increased human activity has threatened many of these species. The natural processes such as crude oil formation, soil formation, waste disposal, nitrogen fixation, biological pest control, pharmaceutical production, dispersal of fruits and pollination are all accomplished by the enormous biodiversity available worldwide [4]. Therefore, these problems are of major concern, as the estimated number of contaminated sites is increasing significantly and is becoming a major challenge worldwide. According to the Environmental Protection Agency (EPA) report, the United States has more than 40,000 contaminated sites till May 2004. In Western Europe, some industrialized countries possess even more contaminated sites in a comparatively smaller area [6]. Major incidents in the past few decades such as the Exxon Valdez oil spill, Minimata disease in Japan, the Union-Carbide Bhopal disaster, large-scale contamination of Rhine river, release of radioactive material in Chernobyl accident and progressive deterioration of aquatic habitats and conifer forests in the Northeastern US, Canada and parts of Europe has revealed the necessity to prevent the escape of effluents into the environment [7].

To overcome these drawbacks, a much better perspective is to completely destroy the pollutants, or to transform them into some biodegradable substances. This approach can be achieved by using a technique known as bioremediation. This acts as an option to clean and safe environment and its resources by destroying various contaminants using natural biological activity. It is considered as safer, cleaner, cost effective and environment friendly technology which generally have a

high public acceptance and can often be carried out at any site. According to van Dillewijn et al. [8] "Bioremediation" is defined as the process by means of various biological agents, primarily microorganisms to degrade the environmental contaminants into less toxic forms. The first patent for a biological remediation agent was registered in 1974, using a strain of *Pseudomonas putida* [9] to degrade petroleum. In 1991, about 70 microbial genera were reported to degrade petroleum compounds [10] and almost an equal number has been added to the list in the successive two decades [11]. U.S. EPA has defined bioremediation agents as microbiological cultures, enzyme and nutrient additives that significantly increase the rate of biodegradation to mitigate the effect of various pollutants. The main advantages of bioremediation: low cost, high efficiency, minimization of chemical and biological sludge, selectivity to specific metals, no additional nutrient requirement, regeneration of biosorbent and the possibility of metal recovery [12]. Bioremediation can occur on its own in nature (natural attenuation or intrinsic bioremediation) or can be spurred via addition of fertilizers for the enhancement of bioavailability within the medium (biostimulation). Bioventing, bioleaching, bioreactor, bioaugmentation, composting, biostimulation, land farming, phytoremediation and rhizofiltration are all examples of bioremediation technologies [13]. On the basis of removal and transportation of wastes, bioremediation technology can be classified as *in situ* and *ex situ*. *In situ* bioremediation involves treatment of contaminated material at the same site, while *ex situ* involves complete removal of contaminated material from one site and its transfer to another site, where it has been treated using biological agents. In the comparison of both methods, it was found that the rate of biodegradation and consistency of process outcome differs between *in situ* and *ex situ* methods. With the need for excavation of contaminated samples for treatment, the cost of *ex situ* bioremediation is relatively high as compared to *in situ*. *In situ* and *ex situ*, both the bioremediation methods depends essentially on microbial metabolism, however, so far *in situ* methods are preferred over *ex situ* for ecological restoration of contaminated soil, water and environment [14]. 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. The U.S. Environmental Protection Agency (EPA) seeks to protect human health and the environment from risks associated with hazardous waste sites, while encouraging development of innovative technologies such as phytoremediation to more efficiently clean up these sites. The term phytoremediation (phyto = plant and remediation = correct evil) is relatively new, coined in 1991. Phytoremediation technologies have generated much interest as cost-effective and environmental-friendly technologies for the cleanup of organic and inorganic pollutants [15]. Plant-based environmental remediation technology has been widely accepted by academic and industrial scientists as a sustainable cleanup technology applicable in both developed and developing nations [16,17].

### 1.1. Mechanisms of Phytoremediation

Phytoremediation is a newly evolving field of science and technology [18] that uses plants to clean up polluted soil, groundwater, and wastewater. Phytoremediation is defined as the use of green plants, including grasses and woody species, to remove, contain, or render harmless such environmental contaminants as heavy metals, metalloids, trace elements, organic compounds, and radioactive compounds in soil or water. This definition includes all plant-influenced biological [19] chemical, and physical processes that aid in the uptake, sequestration, degradation, and metabolism of contaminants, either by plants, soil microbes, or plant and microbial interactions. Phytoremediation takes advantage of the unique and selective uptake capabilities of plant root systems, together with the translocation, bioaccumulation, and contaminant storage/degradation abilities of the entire plant body. Plant-based soil remediation systems can be viewed as biological treatment systems with an extensive, self-extending uptake network (i.e., the root system) that enhances the below-ground ecosystem for subsequent productive use. Phytoremediation avoids excavation and transport of polluted media thus reducing the risk of spreading the contamination and has the potential to treat sites polluted with more than one type of pollutant. Some drawbacks associated with phytoremediation are dependency on the growing conditions required by the plant (i.e., climate, geology, altitude, temperature); large-scale operations require access to agricultural equipment and knowledge; tolerance of the plant to the pollutant affect the success for remediation; contaminants collected in senescing tissues may be released back into the environment in certain seasons; time taken to remediate sites far exceeds that of other technologies and contaminant solubility may be increased leading to greater environmental damage and the possibility of leaching [20].

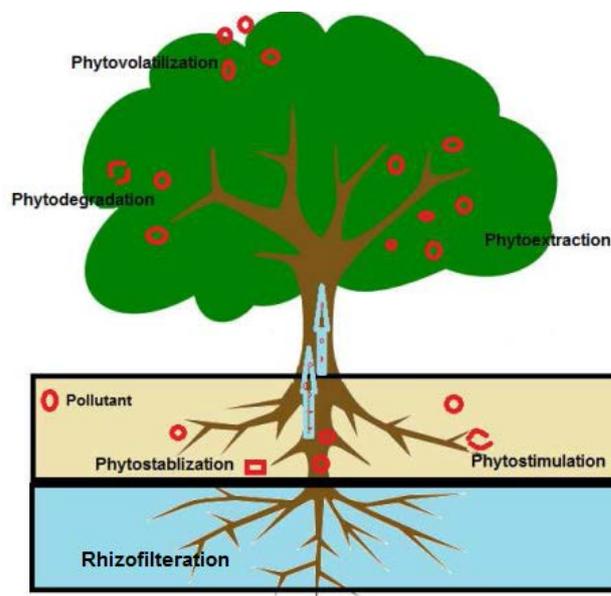


Figure 1. Phytoremediation process

The mechanisms and efficiency of phytoremediation depend on the type of contaminant, bioavailability and soil properties [21]. There are several ways by which plants clean up or remediate contaminated sites. The uptake of contaminants in plants occurs through the root system, in which the principal mechanisms for preventing toxicity are found. The root system provides an enormous surface

area that absorbs and accumulates water and nutrients essential for growth along with other non-essential contaminants [22]. Seven mechanisms by which plants can affect contaminant mass in soil, sediments, and water. Although many similarities can be observed between some of these mechanisms, and the nomenclature varies. Each of these mechanisms will have an effect on the volume, mobility, or toxicity of contaminants, as the application of phytoremediation is intended to do [23].

### 1.1.1. Phytoextraction

This also called phytoaccumulation, it refers to the uptake of metal contaminants in the soil by plant roots into the above ground portions of the plants. Phytoextraction is primarily used for the treatment of contaminated soils<sup>24</sup>. This approach uses plants to absorb, concentrate, and precipitate toxic metals from contaminated soils into the above ground biomass (shoots, leaves, etc.). Discovery of metal hyperaccumulator species demonstrates that plants have the potential to remove metals from contaminated soils [25]. A hyperaccumulator is a plant species capable of accumulating 100 times more metal than a common non-accumulating plant. Metals such as nickel, zinc and copper are the best candidates for removal by phytoextraction because it has been shown that they are preferred by a majority of plants (approximately 400) that uptake and absorb large amounts of metals. There are several advantages of phytoextraction. The cost of phytoextraction is fairly low, when compared to conventional methods. Another benefit is that the contaminant is permanently removed from the soil. In addition, the amount of waste material that must be disposed of is substantially decreased [26] (up to 95%) and in some cases, the contaminant can be recycled from the contaminated plant biomass. The use of hyperaccumulator species is limited by slow growth, shallow root system, and small biomass production. In addition, the plant biomass must also be harvested and disposed of properly. There are several factors limiting the extent of metal phytoextraction including:

- Metal bioavailability within the rhizosphere
- Rate of metal uptake by roots
- Proportion of metal “fixed” within the roots
- Rate of xylem loading/translocation to shoots
- Cellular tolerance to toxic metals

The method is also usually limited to metals and other inorganic compounds in soil or sediment. In order 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 [27].

### 1.1.2. Rhizofiltration

This is used to remediate extracted groundwater, surface water, and wastewater with low contaminant concentrations. It is the adsorption or precipitation onto plant roots or absorption of contaminants surrounding the root zone. Rhizofiltration is typically exploited in groundwater (either in situ or extracted), surface water, or wastewater for removal of metals or other inorganic compounds. Rhizofiltration can be used for Pb, Cd, Cu, Ni,

Zn, and Cr, which are primarily retained within the roots. Rhizofiltration is similar to phytoextraction, but the plants are used contaminated ground water rather than soil. To acclimatize the plants, once a large root system has been developed, contaminated water is collected from a waste site and brought to the plants where it is substituted for their water source. The plants are then planted in the contaminated area where the roots take up the water and the contaminants along with it. As the roots become saturated with contaminants, they are harvested. Sunflower, Indian mustard, tobacco, rye, spinach, and corn have been proved for their ability to remove lead from water, with sunflower having the greatest ability. The advantages associated with rhizofiltration are the ability to use both terrestrial and aquatic plants for either *in situ* or *ex situ* applications. Another advantage is that contaminants do not have to be translocated to the shoots. Thus, species other than hyperaccumulators may be used. Terrestrial plants are preferred because they have a fibrous and much longer root system, increasing the amount of root area. Disadvantages include the constant need to adjust pH, plants may first need to be grown in a greenhouse or nursery; there is periodic harvesting and plant disposal; and a good understanding of the chemical speciation/interactions is needed.

### 1.1.3. Phytovolatilization

This involves the use of plants to take up contaminants from the soil, transforming them into volatile forms and transpiring them into the atmosphere. Phytovolatilization may also refer the diffusion of contaminants from the stems or other plant parts that the contaminant travels through before reaching the leaves. Phytovolatilization can occur with contaminants present in soil, sediment, or water. Mercury is the primary metal contaminant that this process has been used for. It has also been found to occur with volatile organic compounds, including trichloroethene, also as well as inorganic chemicals that have volatile forms, such as selenium, and arsenic. The advantage of this method is that the contaminant, mercuric ion, may be transformed into a less toxic substance. The disadvantage to this is that the mercury released into the atmosphere is likely to be recycled by precipitation and then redeposited back into lakes and oceans, repeating the production of methylmercury by anaerobic bacteria.

### 1.1.4. Phytostabilization

This is also referred to as in-place inactivation. It is used for the remediation of soil, sediment, and sludge. It is the use of certain plant species to immobilize contaminants in the soil and ground water through absorption and accumulation by roots, adsorption onto roots, or precipitation within the root zone of plants (rhizosphere). This process decreases the mobility of the contaminant and prevents migration to the ground water and it reduces bio-availability of metal into the food chain. This technique can also be used to reestablish vegetation cover at sites where natural vegetation fails to survive due to high metals concentrations in surface soils or physical disturbances to surface materials. Metal-tolerant species is used to restore vegetation at contaminated sites, thereby decreasing the potential migration of pollutants through wind erosion and transport of exposed surface soils and leaching of soil contamination to ground water.

Phytostabilization can occur through the sorption, precipitation, or metal valence reduction. It is useful for the treatment of lead (Pb), arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu) and zinc (Zn). Advantage of this method is the changes that the presence of the plant induces in soil chemistry and environment. These changes in soil chemistry may induce adsorption of contaminants onto the plant roots or soil or cause metals precipitation onto the plant root. Phytostabilization has been successful in addressing metals and other inorganic contaminants in soil and sediments. Some of the advantages associated with this technology are that the disposal of hazardous material/biomass is not required and it is very effective when rapid immobilization is needed to preserve ground and surface waters [28]. The presence of plants also reduces soil erosion and decreases the amount of water available in the system. However, this clean-up technology has several major disadvantages including: contaminant remaining in soil, application of extensive fertilization or soil amendments, mandatory monitoring is required, and the stabilization of the contaminants may be primarily due to the soil amendments.

#### 1.1.5. Phytodegradation

This is also referred to as phytotransformation. It involves the degradation of complex organic molecules to simple molecules or the incorporation of these molecules into plant tissues [29]. In the phytodegradation mechanism contaminants are broken down after they have been taken up by the plant. As with phytoextraction and phytovolatilization, plant uptake generally occurs only when the contaminants' solubility and hydrophobicity fall into a certain acceptable range. Phytodegradation has been showed to remediate some organic contaminants, such as chlorinated solvents, herbicides, and munitions, and it can address contaminants in soil, sediment, or groundwater.

#### 1.1.6. Rhizodegradation

This is also referred to as phytostimulation. Rhizodegradation refers to the breakdown of contaminants within the plant root zone, or rhizosphere. It is believed to be carried out by bacteria or other microorganisms. Studies have documented up to 100 times as many microorganisms in rhizosphere soil as in soil outside the rhizosphere. Microorganisms may be so prevalent in the rhizosphere because the plant exudes sugars, amino acids, enzymes, and other compounds that can stimulate bacterial growth. The roots also provide additional surface area for microbes to grow on and a pathway for oxygen transfer from the environment. The localized nature of rhizodegradation means that it is primarily useful in contaminated soil, and it has been investigated and found to have at least some successes in treating a wide variety of mostly organic chemicals, including petroleum hydrocarbons, polycyclic aromatic hydrocarbons (PAHs), chlorinated solvents, pesticides, polychlorinated biphenyls (PCBs), benzene, toluene, ethylbenzene, and xylenes. It can also be seen as plant-assisted bioremediation, the stimulation of microbial and fungal degradation by release of exudates/enzymes into the root zone (rhizosphere) [30].

## 2. Background and World Scenario of Phytoremediation:-

The concept of using plants is not new to clean up contaminated environments. About 300 years ago, plants were proposed for use in the treatment of wastewater [31]. *Thlaspi caerulescens* and *Viola calaminaria* were the first plant species documented to accumulate high levels of metals in leaves [32]. In 1935, Byers reported that plants of the genus *Astragalus* were capable of accumulating up to 0.6 % selenium in dry shoot biomass. One decade later [33], identified plants able to accumulate up to 1% Ni in shoots. More recently [34], reported tolerance and high Zn accumulation in shoots of *Thlaspi caerulescens*. Despite subsequent reports claiming identification of Co, Cu, and Mn hyperaccumulators, the existence of plants hyperaccumulating metals other than Cd, Ni, Se and Zn has been questioned and requires additional confirmation [35]. The concept of using plants to absorb metals from contaminated soil was reintroduced and developed by Utsunomyia and Chaney [36], and the first field trial on Zn and Cd phytoextraction was conducted in 1991 [37]. In the last decade, extensive research has been conducted to investigate the biology of metal phytoextraction. Although significant success, our understanding of the plant mechanisms that allow metal extraction is still emerging. In addition, relevant applied aspects, such as the effect of agronomic practices on metal removal by plants are largely unknown. It is conceivable that maturation of phytoextraction into a commercial technology will ultimately depend on the elucidation of plant mechanisms and application of adequate agronomic practices. Natural occurrence of plant species capable of accumulating extraordinarily high metal levels makes the investigation of this process particularly interesting.

In nature land and water are precious natural resources for the sustainability of agriculture and the civilization of mankind. However, industrialization and urbanization shows maximum exploitation and severe pollution in these resources. Because the Land and water pollution by heavy metals is a worldwide issue [38]. Worldwide all countries have been affected by heavy metal pollution, though the area and severity of heavy metal pollution vary enormously so there has been an increasing concern with regard to accumulation of heavy metals in environment as they pose big threat to both human health and natural environment [39]. In Central and Eastern European countries about 1.7 million sites were affected by heavy metals moreover in USA, there are 600 000 brown fields which are contaminated with heavy metals and need reclamation due to which 1,00,000 ha of cropland, 55,000 ha of pasture and 50,000 ha of forest have been lost [40]. In developing countries particularly in India, China, Pakistan and Bangladesh soil and water pollution is also severe problem where small industries are pouring their untreated effluents in the surface drains, which spread over near agricultural fields. In these countries, raw sewage is often used for producing vegetables [41]. Cadmium salts is significant water pollutants not only because of their direct toxicity in water but also due to their ability to incorporate into the food chain by aquatic plants and organisms with the natural process of bioaccumulation and biomagnification [42]. The annual worldwide release of cadmium is about 9,39,000 tones [43]. Mobilization of heavy metals in environment due to the industrial activities is of serious problem due to toxicity of these metals in human and other forms of life

[44]. Removal of toxic heavy metals from industrial wastewater is essential for today Human life of environmental pollution control [45]. In order to maintain good quality of soil and water there are continuous efforts have been made to develop technologies that are easy to use, sustainable and economically feasible. Physicochemical approaches have been widely used for remedying polluted soil and water. However, they experienced more difficulties for a large scale of remediation because of high initial capital cost, larger volume of chemicals, continuous maintenance, skilled technicians and even generate large amount of sludge which adds into the secondary waste generation, posing threats to aquatic life and minimizes the acceptability of the treatment technique [46]. The use of plant species for cleaning polluted soils and waters named as phytoremediation has gained increasing attention since last decade, as an emerging cheaper technology. Pollution of the environment by metals and organic contaminants is a world wide problem. In literature we have found that in the EU there may be up to 3.6 million potentially contaminated sites [47]. Over 80,000 sites have been cleaned up over the last 30 years, 250,000 still require urgent attention [48]. For the US, there is no comprehensive list of the number of contaminated sites, much less an analysis of the degree of contamination at various locations. The number of Superfund sites listed in the National Priorities List lies at 1289 in April 2011. Although the EU (European Union), in its Communication on the Thematic Strategy for Soil protection, does not mention the high cost of effective soil cleanup as a cause for the lagging behind in soil remediation [49], it does suggest that a future Soil Framework Directive should allow Member States to select remediation strategies which they consider most cost-effective. For the US, estimated market costs for cleanup of all polluted sites is \$ 209 billion for a total of 294,000 sites [50]. Moreover, there is a European [51] and international movement toward risk based land management, a management strategy that does not necessarily lead to a removal of all toxic substances present, but rather of the available ones [52] which may harm human health or the general environment, not only while in soil, but also after remediation. Also, it is widely recognized that (conventional) cleanup activities of hazardous waste sites may be the cause of external effects such as the emission of greenhouse gases by the use of heavy duty construction equipment powered by diesel fuel [53,54]. It seems obvious that any remediation work should be in line with sustainable development or it would not make sense at all to remediate [55]. In Europe, Vegter pointed out in the context of the Clarinet European platform that sustainable contaminated land management should include the need for sustainable development besides the choice of an appropriate remediation technology [56,57]. In the US, the Environmental Protection Agency published the Superfund Green Remediation Strategy which outlines strategic recommendations for cleaner site redevelopment [58]. From the end of the nineteenth century until the mid 1970s, zinc (Zn) and lead (Pb) were refined at several locations in the Campine region (northeast of Belgium and south of the Netherlands) using a pyrometallurgical process [59,60]. As a result, a large area of 700 km<sup>2</sup> is shallowly contaminated due to atmospheric deposition,

with cadmium (Cd), Pb, and Zn as the main pollutants [61]. Flemish soil standards are exceeded for Cd only [62,63]. Moreover, large areas of this contaminated land are currently in agricultural use [64]. The soils in the region are characterized by a sandy texture and relatively low pH [65] which entails an enhanced risk for uptake of these metals in crops and leaching to the groundwater, resulting in food and fodder crops that often exceed European and Belgian legal threshold values for Cd [66,67,68,69]. This imposes a serious threat on the profitability of the farming industry and led the Public Waste Agency of Flanders to decide that these soils need proper management, if possible through remediation. There are many remediation technologies available for contaminated soils, however, few are applicable to heavy metal contaminated ones due to the immutable and relatively immobile character of metals [70]. Besides the enormous cost of conventional technologies (at a cost of \$ 54 m<sup>-3</sup> and a contamination depth of 40 cm, the cost of conventional remediation would be \$ 215,000 per ha, with in Belgium alone 28,000 ha lying waiting for a solution), there are also practical problems such as the availability of suitable replacement soil in case of excavation. Conventional technologies, although they would be capable of remediating the land within a limited amount of time, tend to destroy every biological activity in soil, which would mean that after remediation agricultural activities would no longer be possible. Cultivation of crops with moderate to high metal accumulation capacities on these metal contaminated soils could allow to gradually reduce the available metal fractions in soil. This principle is known as metal phytoextraction [71]. Phytoextraction could be a cost-effective, sustainable, risk managing technology with costs similar to farming costs [72,73,74,75], minimizing energy, water, and material use while protecting land and ecosystems. Issues concerning the fact that these energy crops are often grown on land destined for food production could be avoided by producing biofuel feedstocks on marginal land that is not suited to grow crops for food- and fodder purposes [76]. This marginal land comprises soils that either lack nutrients, receive little rain, or have been contaminated due to previous industrial or agricultural activities. Schreurs et al. showed, based on GIS maps indicating Cd contamination levels in the Campine region, that over 2000 ha of agricultural texture and relatively low pH which entails an enhanced risk for uptake of these metals in crops and leaching to the groundwater, resulting in food and fodder crops that often exceed European and Belgian legal threshold values for Cd. This imposes a serious threat on the profitability of the farming industry and led the Public Waste Agency of Flanders to decide that these soils need proper management, if possible through remediation. There are many remediation technologies available for contaminated soils, however, few are applicable to heavy metal contaminated ones due to the immutable and relatively immobile character of metals [77].

Plant Family has a worldwide distribution. There are many species of economical value, for example vegetable plants, plants used for obtaining of dyes, oil, etc. There are also many ornamental plants. The best known member of family is *Arabidopsis thaliana*, plant noted as a model for molecular biology. More than 400 plant species belonging

to 45 plant families have been identified and reported from temperate to tropical regions with the ability to tolerate and hyperaccumulate heavy metals. These plants have been considered suitable for soil stabilization and extraction of heavy metals. Hyper accumulator plants can play a key role in the fate of the pollutants of contaminated matrixes via their root systems. According to Freidland [78]. An ideal plant species for phytoremediation should have either one of the following characteristics: (a) a low biomass plant with a very high metal accumulation capacity or (b) a high biomass plant with enhanced metal uptake potential. Metal tolerant plants with lower metal accumulation are preferred for phytostabilization & heavy metal hyperaccumulators are the best choice for phytoextraction as they tolerate high metal ions through various detoxification mechanisms which may include selective metal uptake, excretion, complexing by specific ligands & compartmentation of metal ligand complexes [79,80]. The most important used family in phytoremediation is Brassicaceae contains high number of species that are able of hyperaccumulation of heavy metals, especially nickel (genera *Thlaspi* and *Alyssum*), cadmium and zinc (*Thlaspi caerulescens*, *Thlaspi praecox*, *Thlaspi goesingense* and *Arabidopsis halleri*). About 25% of all known hyperaccumulators are members of this family [81,82,83]. Based on the literature from 1995 until 2009, it can be stated that the most frequently cited species in phytoremediation studies was *Brassica juncea* (L.), *Brassica napus* L. and *Zea mays* L. The greater interest in *Brassicaceae* derives from the fact that research on these species started earlier, together with the interesting concentrations they provide, especially for *Brassica juncea* [84]. Among the plants of the *Brassica* species, the *Brassica juncea* deserve most attention because its relevance to the process of phytoextraction of heavy metals from soil was confirmed in many experiments. It has been found that *B. juncea* exhibits a high capacity to accumulate Cd mainly in the shoots, where Cd level was recorded at level of 1450 µg Cd/g dry wt. This is three times more than reported in *Brassica napus* (555 µg/g dry wt) [85]. In addition, this plant exhibit a high removal efficiency of other metals such as Pb (28% reduction) and Se (reduced between 13–48%) [86]. In addition, this plant is more effective at removing Zn from soil than *Thlaspi caerulescens*, a known hyperaccumulator of zinc. This is due to the fact, that *B. juncea* produces ten-times more biomass than *T. caerulescens* [87]. However *Brassica juncea* needs to be harvested shortly after the plant becomes mature, which causes problems of disposal of obtained biomass.

### 3. Phytoremediation in Global Prospects:-

World is divided into 7 continents. The term continent is used to differentiate between the various large areas of the earth into which the land surface is divided. So, a continent is "a large, continuous area of land on Earth". All continents together constitute less than one-third of the earth's surface, that means more than two-thirds of the earth's surface are covered with water. Two-thirds of the continental land mass is located in the Northern Hemisphere.



Figure 3.1. Map showing different continents in world

Phytoremediation research is going on in every continents. But most of the work has been done in US, Africa and Asia. The science of phytoremediation has shown promising results as an innovative cleanup technology. However, it is still in a developmental stage and more research is needed to increase the understanding and knowledge of this remediation technology. One of the major problems encountered with the phytoremediation of heavy metals is their decreased bioavailability to plants. Generally, soil amendments are added to the soil to increase the bioavailability of heavy metals to enhance the uptake by plants. A number of environmental concerns pertaining to the use of soil amendments have arose and will be addressed in a later section. Ongoing bench-scale studies and field demonstrations are being conducted throughout the United States in order to better understand and implement this technology. As phytoremediation progresses it is expected to increase its share in the environmental cleanup market. D. Glass Associates, Inc. has already estimated a projected market for the field of phytoremediation. For 1998, the projected market was \$16.5-\$29.5 million, the year 2000 market was estimated at \$55-\$103 million, and by the year 2005, it has been estimated to reach \$214-\$370 million [88]. In some of the countries phytoremediation technology accepted and work is going on, which are following:-

#### 3.1. Phytoremediation in US

According to a 1997 report it is estimated that there are almost half a million contaminated sites throughout the United States and more than 217,000 of them are still in need of remediation [89]. The national clean-up market consists of the Environmental Protection Agency's (EPA) Superfund sites and RCRA, Department of Defense (DOD), Department of Energy (DOE), State sites, and Private Party sites. Superfund sites are the most contaminated hazardous waste sites located in the United States and are on the National Priorities List (NPL). RCRA, the Resource Conservation and Recovery Act, regulates hazardous waste treatment, storage, and disposal facilities. Sixty-four percent of Superfund and RCRA sites are contaminated with both organic and heavy metal species and another 15% are contaminated solely by metals. Eleven percent of the DOD's 7313 sites, covering 26,000 acres, are contaminated with heavy metals. The DOE has 4,000 sites, 23 of them listed as Superfund sites, with 53% contaminated with organic compounds and heavy metals and 7% with metals alone. There are 19,000 state-owned sites with 38% containing heavy metals and organics and 7% with only metals. The number of Private sites in need

of remedial action has been estimated at 24,000 [90]. The most common heavy metals at hazardous waste sites are Cadmium (Cd), Chromium (Cr), Copper (Cu), Lead (Pb), Mercury (Hg), Nickel (Ni) and Zinc (Zn). Of these, lead and mercury are two of the most significant contaminants, posing serious and sometimes life threatening health hazards. Lead, which contaminates more than 50% of sites found on the NPL, is one of the most prominent metal contaminants found in hazardous waste sites [91]. Mercury also poses significant environmental and health concerns. The World Health Organization (WHO) has approximated that each year 10,000 tons of mercury are released globally from both natural and anthropogenic sources [92].

Due to the extreme consequences, environmental contamination with heavy metals, particularly lead and mercury, is a significant concern. Now faced with these overly extensive environmental problems, a cost-effective means of remediation pertinent to the contaminated areas must be found. There are a number of conventional remediation technologies which are employed to remediate environmental contamination with heavy metals such as solidification, soil washing and permeable barriers. But a majority of these technologies are costly to implement and cause further disturbance to the already damaged environment. Phytoremediation is evolving as a cost-effective alternative to high-energy, high-cost conventional methods. It is considered to be a "Green Revolution" in the field of innovative cleanup technologies. Phytoremediation has the potential to clean an estimated 30,000 contaminated waste sites throughout the US according to the EPA's Comprehensive Environmental Response Compensation Liability Information System (CERCLIS). Sites included in this estimate are those that have either been owned or contaminated by: battery manufacturers, electroplating, metal finishing, and mining companies. Also included in the estimate are producers of solvents, coated glass, paints, leather, and chemicals [93]. Phytoremediation is aimed at providing an innovative, economical, and environmentally-friendly approach to removing toxic metals from hazardous waste sites [94].

### 3.2. Phytoremediation in Europe

Use of phytotechnologies in Europe is limited, as compared with USA and Canada. In those countries, private companies have been formed with the purpose to apply plant resources to control pollution [95]. European normative and public opinion are still precautionary in the use of phytoremediation. The following constraints have been evidenced:

- due to limited knowledge and poor dissemination, there are doubts in the public opinion and limited acceptance,
- the current regulations, which do not clearly consider phytoremediation within the current applicable technologies
- unfavorable competition with standard clean-up methods, which can provide a long-standing record of success
- lack of sufficient investments, for encouraging the private initiative

- proprietary rights, which may hinder application of approaches already proved as successful in USA

One of the main constraints, however, rests on the lack of fundamental and applied research. In fact, research on the basic mechanisms of phytotechnologies and case studies are still needed in order to use these technologies in a coherent way. Moreover, in the last Framework Programme of the European Commission there was no topic really suitable for presentation of projects on phytotechnologies, and most of the European scientists have to rely on small budgets obtained from National or Regional sources. Nevertheless, the EC has recently funded projects on this topic, as listed in the CORDIS web site, which have avoided a complete blockage of research in phytoremediation. Another tool which was instrumental to maintain interest in phytoremediation and phytotechnologies has been the COST Action 837 "Plant biotechnology for the removal of organic pollutants and toxic metals from wastewaters and contaminated sites" and the new one, 859. A survey, carried out in April 2005, enlisted all scientists involved in phytotechnology research in Europe which could be found in publications indexed by ISI (Current Contents) and/or those who participated to the COST meetings. The countries involved were 29, including Israel and Turkey which participate to European projects. About 350 research groups were involved, of which 60% were in Universities, 30% in research institutes and 10% in private companies. Indeed this distribution of efforts may be biased by industrial research which, for competition problems, is limited in dissemination through journals. From papers published in 2001-2004, the distribution of topics for research is the same in Europe as in the USA, with most of the efforts concentrated on understanding the basic principles of phytotechnologies. A new trend is in the field of management and sustainability of enabling technologies. At this purpose different papers concern risk assessment and utilization of Decision Support Systems. Research on phytoremediation and phytotechnologies is thriving in Europe even despite lack of funding. Few EC funded projects and different National or regional activities have prevented research in this field to collapse. Networking activities such as those promoted within cost are also of extreme importance for building interactions and collaboration among scientists within and outside Europe. Other initiatives targeted at dissemination, education and training, should be activated in order to increase the familiarity and confidence of the public opinion and of stakeholders in these new sustainable technologies [96].

### 3.3. Phytoremediation in South Africa

The concentrations of anthropogenic toxic substances in the environment has risen beyond set limits, although quantitation of such increase had been difficult to ascertain, annual estimation of the spread has been reported to be in billions of tons [97,98]. In South Africa for example, industrialization has resulted to an increase in industrial waste of environmental concern. This sudden rise in waste generation could result in dysfunctional hydrology as well as acidification and salination of the soil and groundwater leading to nature cycling and environmental degradation. Environmental degradation

causes loss in biodiversity and the ecosystem which eventually impacts on human health if proper measures are not employed to checkmate it [99,100]. There are different types of contaminants found in the environment. The most dangerous among them are those that have high persistence in bioaccumulation as well as toxicity capabilities to man as they occur in the food chain. Persistent organic pollutants (POPs), as those contaminants are called and which include polychlorinated biphenyls (PCBs) accumulate in different niches of biosphere significantly affecting ecological balance [101]. The international character of environmental degradation determined by factors such as global migration of contaminants (migration between soil, air and water), consists in overall distribution of contaminants of different structure and level of toxicity [102]. Plants which are regarded as a natural ecological tool occupying approximately 47% of the total land surface of the earth are capable of purifying the air, water and soil. This means that plants are potential universal detoxifiers. It has been reported that plants in addition to accumulation of heavy metals, carry out intracellular degradation process which leads to decomposition of carbon skeleton of different contaminants [103].

In one case study of South Africa, AngloGold Ashanti has planted around half a million trees over the last decade for research on using phyto (plant) technologies to prevent and repair environmental impacts from the company's tailings storage facilities (TSFs) in South Africa. Most TSFs emit dust and seepage containing salts and metals which can contaminate the surrounding environment. Thus the "Ecological Engineering and Phytoremediation Research Programme" was initiated in 1995 by AngloGold Ashanti (then Anglo American Gold Division) and the School of Animal, Plant and Environmental Sciences (APES) of the University of the Witwatersrand, Johannesburg (Wits University). Around 80 species of plants have been assessed to date in tailings experiments, and almost 60 species of trees are being assessed in woodlands trials on seepage from TSFs. It is expected that approximately 200 plant species will eventually be used out of the almost 600 species found to grow naturally on the reef outcrops, polluted soils and tailings.

Since 2000, research has focused on the effectiveness of different types of vegetation in groundwater and soil remediation. This builds on the earlier research by Wits University and AngloGold Ashanti which has shown that native plants and micro-organisms grow naturally in hostile mine environments, and how they can be propagated and grown to potentially rehabilitate TSFs and polluted soils. In 2006, Wits University and AngloGold Ashanti's Environmental Management Department received an award for their scientific research from the National Research Foundation and the Department of Trade and Industry of South Africa. Some of the "phytotechnologies" identified during the research will start being implemented on three TSFs and selected sites at AngloGold Ashanti's West Wits and Vaal River operations between 2009 and 2012 at an estimated cost of R4,000 to R40,000 per hectare. The aim is to use natural processes to convert mine waste to natural resources, and thereby achieve sustainable rehabilitation of entire mines. This involves preventing pollution through the strategic planting of different types of native woodland for

evaporative and hydraulic control on and around TSFs, and fostering of the wetlands and riverside woodlands that cleanse water; the decontamination of soil and water through the planting and harvesting of plants that are able to concentrate pollutants in their leaves; and the use of plants to develop 'soil' directly in tailings. The fostering of an enabling environment through education, public-private partnerships and community-business development is important if the project is to be successful. Many South Africans depend on plant products for poverty alleviation, and some of the plants found to grow on the company's TSFs are known to have useful properties. The final phase of the research (taking place between 2009 and 2012) will look at how phytoremediation plants might be able to produce materials for secondary industries, and thus help local communities. Such materials might include precious woods, fibres, chemicals, essential oils, dyes, gums and recoverable minerals and metals.

### 3.4. Phytoremediation in ASIA

#### 3.4.1. INDIA

In India, urbanization, excessive utilization of natural resources, and population growth are the causes for air, water, and soil contamination and pollution. Major environmental problems in India are land degradation (deforestation, overgrazing, overcultivation, faulty irrigation), destruction of wildlife habitat and erosion of genetic resources (including those of crops and trees, terrestrial animals, and fish), and pollution (air, water, and soil pollution with toxic wastes and other substances). Soil conservation and restoration of degraded soils (wasteland/marginal land) is the most serious environmental concern to India. In India, soil erosion is a serious problem ranging from loss of top soil in 130.5 million ha to terrain deformation in 16.4 million ha. Soil loss under different land-use options has been reported and minimum loss found when trees and grass were grown together in a silvipastoral system. For e.g., Shivaliks (foothills of Himalayas, one of the most fragile ecosystems) has included combinations of eucalyptus-bhabar grass; Acacia catechu-forage grass; Leucaena-Napier grass; teak-Leucaena-Bhabar; Eucalyptus-Leucaena-Turmeric; poplar-Leucaena-Bhabar; and Sesamum-rape seed. Sodic soils of the Indo-gangetic alluvial plain are characterized by high pH, high exchangeable sodium and phosphorus, low infiltration, dispersed soil, low organic matter content, and poor fertility. Special planting techniques have been developed for raising multipurpose tree species in sodic and saline soils. A silvipastoral model comprising *Prosopis juliflora* and *Leptochloa fusca* has been developed, and alkali soils have been standardized. Another serious problem is the physical deterioration of soil because of water logging or submergence/flooding that has affected around 11.6 million ha of land in India. Suitable trees and grass species for such situations are trees (*Eucalyptus tereticornis*, *Populus deltoids*, *Terminalia arjuna*, *Acacia auriculiformis*, *Syzigium cumini*, *Albizia lebbek*, *Dalbergia sissoo*, and *Pongamia pinnata*) and grasses (para grass, cord grass, lemon grass, and *Setaria* grass). Contamination of food and other agricultural products with pesticide residues is a widespread problem in India. India's 15 oil refineries generate a huge amount of oily

sludge annually. This also takes a toll on the scarce soil, because land requirements increase with an increase in oil sludge generation. Besides the sludge from oil refineries, crude oil spills too are a cause of environmental degradation. The "Mission Mode" experiment of fly-ash management including using fly ash in forestry systems is one of the important strategies to protect environmental degradation [104].

A phytoremediation study was carried out at Pariyej reservoir, an internationally important wetland listed in Asian Directory of Wetlands, designated as a "Wetland of International Importance" and a proposed community reserve of Gujarat State, India, to ascertain the degree of heavy metal contamination. The study focused on assessment of heavy metal accumulation in certain aquatic macrophytes used as biomonitors, in comparison with water and sediments (abiotic monitors) for phytoremediation. Roots, stems and leaves of native aquatic plants (biomonitors) represented by seven species: *Ipomoea aquatica* Forsk, *Eichhornia crassipes*, (Mart.) Solms, *Typha angustata* Bory & Chaub, *Echinochloa colonum* (L.) Link, *Hydrilla verticillata* (L.f.) Royle, *Nelumbo nucifera* Gaerth. and *Vallisneria spiralis* L. along with surface sediments and water, were analyzed for Cd, Co, Cu, Ni, Pb and Zn contamination. The greater accumulation of heavy metals was observed in *Nelumbo nucifera* and the poor content in *Echinochloa colonum*. Based on the concentration and toxicity status observed in the lake's vegetation, the six heavy metals are arranged in the following descending order: Zn > Cu > Pb > Ni > Co > Cd compared with the standard, normal and critical toxicity range in plants. The detected values of Cd and Pb fall within normal range, while that of Co and Ni were within the critical range. However, Zn and Cu showed the highest accumulation with alarming toxicity levels, which are considered as one of the most hazardous pollutants in Pariyej reservoir. Species like *Typha angustata* and *Ipomoea aquatica* are also proposed as bioremediants, which are the two most useful plant species in phytoremediation studies due to their ability to accumulate heavy metals in high concentration in the roots. The results showed the significant differences in accumulation of metals like Zn, Cu and Pb in different plant organs, in roots than that of stems and leaves. High positive correlation between combinations of different metal pairs in plant's root, stem or leaf system was established. The potential use of these wetland plants in phytoremediation is also discussed [105].

This review presents the status of phytoremediation technologies with particular emphasis on phytoextraction of soil heavy metal contamination. Unlike organic compounds, metals cannot be degraded, and cleanup usually requires their removal. Most of the conventional remedial technologies are expensive and inhibit the soil fertility; this subsequently causes negative impacts on the ecosystem. Phytoremediation is a cost effective, environmental friendly, aesthetically pleasing approach most suitable for developing countries. Despite this potential, phytoremediation is yet to become a commercially available technology in India. This paper reports about the mobility, bioavailability and plant response to presence of soil heavy metals. It classifies the plants according to phytoextraction mechanism and discusses the pathway of metal in plants. Various

techniques to enhance phytoextraction and utilization of by-products have been elaborated. Since lot of biomass is produced during this process, it needs proper disposal and management. It also gives an insight into the work done by authors, which focuses on high biomass extractor plants. High biomass weeds were selected to restrict the passage of contaminants into the food chain by selecting non-edible, disease resistant and tolerant plants, which can provide renewable energy. Thus making phytoextraction more viable for present utilization [106]. The conventional wetland system using *Phragmites* sp. is in existence since 20 years. The constructed wetland system has not gained much popularity due to large land area requirement, clogging of beds and need for capital investment. The aim of the study is to develop a new approach to the horizontal flow wetlands system (termed bio-rack) for treatment of domestic wastewater. The new system dealt with an engineered attached growth matrix and a high microbial degradation rate. The study on bio-rack was undertaken in a horizontal flow pilot plant using *Phragmites* sp. and experiments were carried out for various parameters. Analytical data were collected during the studies which include temperature, pH, chemical oxygen demand (COD), biological oxygen demand (BOD5), dissolved oxygen (DO), chlorides, total dissolved solids (TDS), total suspended solids (TSS), ammonia nitrogen (NH<sub>3</sub>-N), phosphate (PO<sub>4</sub>-P) and most probable number (MPN). This paper also studies microbial flora present in the system by isolating and identifying the microorganisms, and also measuring total viable count (TVC). Morphological aspects with reference to the growth of plant were studied and it indicated high plant yield. At optimum hydraulic retention time (HRT) of 10 h, approximately 75.15% COD, 86.59% BOD5, 27.54% TDS, 73.13% TSS, 8.86% Chlorides, 70.22% NH<sub>3</sub>-N, 31.71% PO<sub>4</sub>-P and 92.11% MPN reduction was achieved in bio-rack system. A comparative evaluation was done with the conventional wetland system and better treatment efficiency was observed in the bio-rack system. This result indicates a possibility of development of a substantially effective system compared to any other methods on constructed wetland [107].

### 3.4.2. Indonesia

This study aims to determine the best type of local plants as aquatic plants phytoremediation candidate in acid mine water management system with a passive model of wetland / aerobic wetland rise by testing several kinds of local plants around the coal mines as a medium of Phytoremediation. System used multilevel methods to be more effective in lowering the levels of acid, metals absorb capability and in accordance with the characteristics of each of these plants. Local plants used in order to found a new species that is easy to apply in the field and also to reduce costs and also more friendly to the surrounding ecosystem-especially in the coal mining company in South Kalimantan and generally in Indonesia. Management of acid mine water by means phytoremediation using aerobic wetland system to test 5 different water plants as candidates who are at the mine, namely: 1. *Eleocharis dulcis*, 2. *Cyperus odoratus*, 3. *Hydrilla Vercilata*, 4. *Ipomea aquatic*, 5. *Pistia Stratiotes* with a retention period of each plant for 29 demonstrate the ability to reduce the acid levels in the

water to raise the pH of acid mine average of 41% and lower levels of iron (Fe) with an average index bioremediation 7% and lower levels of manganese (Mn) with an average of 19% index bioremediation. The best candidates phytoremediation plants to lower acid levels by raising the pH is Kale Water (*Ipomea aquatic*) to raise the pH of 53%. To reduce levels of iron in acid mine water is to use *Eleocharis dulcis* reduce levels of iron (Fe) 70% to reduce manganese from the water so it is *Pistia Stratatiotes* lower levels of manganese (Mn) as much as 55% [108].

### 3.4.3. PAKISTAN

Presence of heavy metals and other pollutants in the aquatic systems has become a serious problem in many developing countries for environmental scientists and also for agencies engaged in environmental production. In this regard, there has been a great deal of attention given to new technologies for removal of heavy metals from contaminated water because conventional technologies to provide safe and clean water to living beings are not so far implemented. In this manner, the use of plants to remove heavy metals and other pollutants known as “phytoremediation” from the water is relatively cheaper as compared to other expensive engineering operations as plants remove pollutants from water and render them harmless. Five main subgroups of phytoremediation have been identified by the environmental scientists as “Phytoextraction, Phytodegradation, Rhizofiltration, Phytostabilisation and Phytovolatilisation”. The identification and selection of plants that are suitable for successful remediation of water pollution is a matter of great concern. It is recommended that plants that have long and extensive root system should be planted at sites which are polluted due to industrial and sewage water [109].

### 3.4.4. Bangladesh

Wastes generated from the leather processing industries located in the southwestern part of Dhaka, the capital city of Bangladesh, pose serious threat to the environment. Groundwater as well as the ecosystem of the area are on the verge of huge pollution making its way to be recognized sooner or later as one of the most polluted City in south Asia due to industrial activities. As chromium(Cr) is widely used in many types of industries, wastes from tanneries pose a serious threat to the environment. Present research conducted greenhouse pot experiments on several plant species to find out the phytoextraction potential of these plants to remove Cr from contaminated soils. *Urtica dioica*, a common nettle, proved to be the most potential candidate for this purpose with minimal addition of potassium (K) as nutrient solution [110].

### 3.4.5. CHINA

The excessive growth of water hyacinth is a common environmental problem in tropical regions. The use of water hyacinth to remove nutrients from bodies of water and to produce biogas is a technically feasible way of controlling water hyacinth, but its environmental and economic performance are not well understood. This study collected data from an experimental biogas plant to develop a lifecycle analysis and a cost benefit analysis for

the control of water hyacinth in Dianchi Lake, a eutrophic lake in China. A comparison was made between the proposed project and the current approach at Dianchi Lake of disposing of water hyacinth via collection and landfill. The results revealed that the proposed project is economically feasible with a desirable energy gain. The results also showed that the project is not financially feasible but, compared to the current landfill practice, the government would be able to spend less on controlling water hyacinth if they implemented the proposed project. The removal of water hyacinth to produce biogas can also contribute to water quality improvement and GHG emission reduction; however, these values depend on the scale of processing undertaken by the biogas plant. Since both the current approach and the proposed project can remove nutrients from bodies of water, the additional value resulting from the proposed project of an improvement in water quality only becomes possible when the processing scale of the biogas plant is greater than the amount of water hyacinth disposed of by landfill. The proposed project can avoid methane emissions when the processing scale is greater than the amount of water hyacinth currently disposed of via landfill. The internalization of GHG emission reduction alone is not sufficient to make the project financially feasible and therefore other sources of compensation are needed in order to promote the production of biogas from water hyacinth. The proposed project could be a potential microeconomic option, which could respond to China’s macro water pollution control policies, renewable energy development, and energy saving and emissions reduction. However, institutional arrangements are required to coordinate these diverse policies when they are applied to the proposed project. The results revealed that the project is economically feasible and has a desirable energy gain. The results also revealed that the project is not financially feasible but to achieve the same level of control over water hyacinth in the without-project scenario, the government would spend less money on the control of water hyacinth if they were to implement the proposed project. In order for firms to breakeven, the municipal government has to pay 104.8 Yuan per tonne-1 of disposed water hyacinth using the current practice but would pay only 66.8 Yuan a tonne-1 if the proposed project were implemented. Moreover, the project is desirable in terms of energy performance. For disposing of 11,004.2 tones of water hyacinth, the project has an energy gain of 5.3 trillion joules while the current approach has an energy loss of 162.9 billion joules. The results of this study have significant policy implications. The proposed project represents a better policy option than the current approach to disposal of water hyacinth by landfill in terms of both environmental and economic performance. The project has potential as a microeconomic option in response to China’s macroeconomic policies on water pollution control, renewable energy development, and energy saving and emission reduction [111].

## 3.5. Phytoremediation in Australia

Phytoremediation in Australia stemmed from pioneering work by Professor R.R. Brooks on plant that hyperaccumulate heavy metals. Although work focused on the extraction of heavy metals from contaminated sites,

successful phytoremediation now employs plant as biopumps to reduce contaminant mobility and entrance the in-situ degradation of some pesticides. In the first year of 21 century phytoremediation became established in the commercial environment with the appearance of dedicated phytoremediation companies. Phytoremediation offers a low cost means of maintaining Australia its greatest potential is the remediation of mining affected lands.

In Australia the botany department at the University of Melbourne the centre for mined land rehabilitation, the commonwealth scientific and industrial research organization (CSIRO) and several universities have phytoremediation programmes. Phytolink Australia is a dedicated phytoremediation company. Phytoremediation in Australia has focused on the use of plants as biopumps [112]. Plant use the Sun's energy to dewater contamination sites and control leaching as well as entrance the organic matter and microbial activity in the rhizosphere. These root zone processes thereby augment contaminants degradation and reduce the mobility of heavy metals.

In Australia the most important role of phytoremediation is to reduce contaminant mobility and to degrade organic pollutants, rather than the phytoextraction of heavy metals. Australia has over 2 million ha of open cast mining and many contamination sites associated with smelting and processing [113]. The country faces environmental issues associated the disposal and treatment of sewage sludge and burgeoning land fills. Australia often suffers from drought and associated soil salinity, which can negatively affect plant growth, but under phytoremediation effective for the mitigation of leaching. Phytoremediation is best suited to the long term clean up of low value where other remediation options are prohibitively expensive [114]. This technology is therefore well suited for use contaminated sites in the extensive production system of Australia.

Phytoremediation of biosolids, western treatment plant, Victoria, Australia:-

The storage of biosolids, the solid fraction of sewerage waste, is a contentious subject for any developed area. Fresh biosolids or oxidation pond sludge waste has a water content of approximately 70% by weight. When disposed of on land natural drying will occur. Mechanical drying of the fresh water is possible but is costly and is certainly not applicable to previously deposited volumes of waste. Every major populated area in Australia has large volume of unstable, semiliquid waste stored on potentially valuable land. Melbourne water is the largest water utility in Melbourne with a sewerage system of two water treatment plants, the western and eastern treatment plants. Melbourne produces an average 900 million liters of sewage a day, 54% of which is treated by the western treatment plant (WTP) situated on the western shore of port Philip bay near the city of Geeton [115]. The WTP covers 11000 ha of valuable land and discharge approximately 600 liter of treated water daily into Port Philip Bay, therefore treatment methods are used for incoming sewage. An extensive lagoon system is used for peak daily and year round wet weather flow. Land filtration is used during periods of high evaporation between October and April. Grass filtration is used during period of low evaporation between April and October [116].

## 4. Conclusion

The pollution of soil and water with heavy metals is an environmental concern today. Metals and other inorganic contaminants are among the most prevalent forms of contamination found at waste sites, and their remediation in soils and sediments are among the most technically difficult. The high cost of existing cleanup technologies led to the search for new cleanup strategies that have the potential to be low-cost, low-impact, visually benign, and environmentally sound. Phytoremediation is a new cleanup concept that involves the use of plants to clean or stabilize contaminated environments. 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. Phytoremediation is an emerging technology for contaminated sites that is attractive due to its low cost and versatility. It is not a panacea for hazardous waste problems, but it shows tremendous potential in several applications for treatment of metals and organics at sites where contamination is shallow. phytoremediation has been perceived to be a more environmentally-friendly "green" and low tech alternative to more active and intrusive remedial methods. In conclusion, there are real risks associated with phytoremediation that require assessment and identification of management options prior to implementation of any field based operations. Management options using confinement strategies such as onsite processing, discing, harvesting before seed set, and volunteer management, may reduce the likelihood of pollen and seed movement thus reducing potential risks. Data collection, interpretation and communication of risks must be evaluated if phytoremediation is going to find wide public acceptance. This argues for a balanced approach in the discussion of the benefits and risks of phytoremediation. In any discussion of risks, however, specific risks must be considered in comparison to doing nothing – leaving the site unaltered. Risks of phytoremediation must also be assessed compared to the more traditional methods of remediation including, excavation and landfilling, soil incineration, soil washing and vitrification. Traditional methods of remediation have many real risks, both to human and environmental health that must also be considered. Thus, while acknowledging that there are risks associated with phytoremediation, these risks are temporary that last only during the process of phytoremediation. We believe that in most cases phytoremediation risks are small compared to the risks of doing nothing or the financial and engineering risks of 'dig and haul.'

### 4.1. The Future of Phytoremediation

Though phytoremediation technologies are still primarily in research and development phases, various applications have shown potential for success. This has helped to increase interest and research in both public and private sectors, in an attempt to develop phytoremediation into a commercially viable industry. Some key technical hurdles that must be overcome for an industry to develop and grow are: identifying more species that have remedial abilities, optimizing phytoremediation

processes, such as appropriate plant selection and agronomic practices, understanding more about how plants uptake, translocate, and metabolize contaminants, identifying genes responsible for uptake and/or degradation for transfer to appropriate high-biomass plants, decreasing the length of time needed for phytoremediation to work, devising appropriate methods for contaminated biomass disposal, particularly for heavy metals and radio nuclides that do not degrade to harmless substances, and protecting wildlife from feeding on plants used for remediation. In addition to technical barriers, government regulations will also determine the overall success of phytoremediation. Because the remediation industry is compliance driven, phytoremediation technologies must demonstrate their effectiveness at meeting State and Federal regulations. This simply might not be possible in all situations with many current phytoremediation technologies, due to the nature of the contamination (for example, the age of contamination and relative bioavailability of the contaminants). For these technologies, changes in regulatory status and/or continuing technical improvements will be necessary for commercialization. Also, for more heavily contaminated sites, the phytoremediation process runs into the problems with RCRA waste classification. "When contaminated soils are "managed" they become a hazardous waste, triggering RCRA's Land Disposal Restrictions (LDR) and Minimum Technology Requirement (MTR)," according to Dave Sanders, Chevron spokesperson. As a "managed" hazardous waste meeting the LDR requirement, it must be disposed of with the best available technology incineration. MTR prohibits phytoremediation by requiring landfill liners to be laid under the soil, before it can be spread out and seeded. Many facilities may delay phytoremediation because they don't want to trigger LDR and MTR. "The RCRA regulations are looked upon as an impediment for phytoremediation at refineries," said Nelson. There have been recent efforts to reform the RCRA barrier in federal legislative and regulatory committees. Altering or providing temporary exemption from the LDR and MTR requirements, as was done with underground storage tanks would "open the door to a wide number of remedial technologies like phytoremediation and bioremediation," stated Sanders. Because of all the factors needed for success, the likely size and growth rate of a phytoremediation industry are difficult to predict. Because contaminated soils tend to present more bioavailability problems, Scott Cunningham of Dupont believes most initial phytoremediation successes will come in treatment of contaminated surface and ground waters. Industry sources suggest potential sites for soil phytoremediation are areas with low to moderate amounts of contaminants near the surface. Because it may take a relatively long time for phytoremediation to work, the first target contaminants will also likely have to pose no immediate threat to health or risk of further environmental damage. How soon phytoremediation will succeed as an industry is also uncertain. It offers many potential advantages over traditional remediation technologies, particularly its public acceptance and considerably lower cost. If these factors continue to drive government and private research and development, phytoremediation technologies could continue to evolve. If so, some industry experts believe commercialization of certain technologies could occur within the next 5 years.

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