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STUDY ON THE APPLICATION OF PHYTOREMEDIATION OF CONTAMINATED INDUSTRIAL SITES

Melania-Nicoleta BOROŞ, Valer MICLE

Technical University of Cluj-Napoca, 103-105, Muncii Avenue, 400641, Cluj-Napoca, Romania, Phone: 0264 401 622, Fax: 0264 415 054, Email: borosmelania@yahoo.com, Valer.Micle@imadd.utcluj.ro

Corresponding author email: borosmelania@yahoo.com

Abstract

The effect of urbanization and industrialization led in many cases to the deterioration of the environment. During these processes, a lot of contaminants are released and they accumulate in the environment causing important risks. This study presents the technologies of decontamination of industrial sites using phytoremediation. The use of plants to decontaminate polluted sites is a close to nature method. Plants are able to accumulate important amounts of contaminants from soil by uptaking them by roots and transporting them to the aerial parts. Remediation of contaminated sites is a worldwide concern and contributes to the protection and improvement of the environment. One of the solutions is phytoremediation which is a new technology, innovative and with great perspectives. The aim of this study is to characterize the phytoremediation techniques.

Key words*: environment, industrial sites, phytoremediation.*

INTRODUCTION

The pollution of the environment is a major problem worldwide. Many factors affect the environment, but especially the technological progress, population growth and also urban expansion. One of the greatest ecological concern is the soil pollution that can be affected by oil, heavy metals, agrochemicals and different types of waste (Lyubun and Tychinin, 2007).

In urban areas, abandoned sites that were used for industrial purposes must be restored. The contaminated industrial sites are one of the main subjects of remediation strategies. There are also taken into consideration the mining heaps, quarries, dumps etc.

The Commission of the European Communities estimated in 2006 the number of contaminated sites in the European Union at 3.5 million sites. This affects 231 million people and describes a market value of 57 billion euros. The number of contaminated sites is considered to be significantly bigger nowadays. This does not happen only in Europe, but also in well developed countries like United States, Canada, Australia and many countries is Asia (Meuser, 2013).

In the last decade, phytoremediation has developed from a conceptual methodological approach into a technology that is used for the benefit of the environment by cleaning up the organic and inorganic contaminants. In order to be effective, the most important part in the implementation of one of the phytoremediation processes is choosing the suitable plants that can asimilate the contaminants from the studied site (Kvesitadze et al., 2006).

Phytoremediation is worth to be applied because is cost-effective, aesthetically pleasing to the public and also a green solution compared to other remediation strategies (e.g. excavation, chemical in situ stabilization) (Dordio & Carvalho, 2011).

In this context, the study presents the phytoremediation concept and techniques in order to highlight the importance of the applications in different given situations. The decontamination of industrial sites using phytoremediation is important to dealing with serious environmental problems and applying the solution friendliest with nature.

MATERIALS AND METHODS

Phytoremediation is a concept that has been in use since the early 1990s and is composed of a set of natural technologies that use plants to clean up contaminated areas. The term is composed of two words that are part of its definition: phyto – plant and remediation – to recover (Kvetsitadze et al., 2006). So phytoremediation has been defined as "the use of green plants and their associated rhizospheric microorganisms, soil amendments, and agronomic techniques to remove, degrade, or detoxify harmful environmental pollutants" (Kadukova and Kavuličova, 2011).

Phytoremediation involves the set of technologies that use plants with their microorganisms, enzymes, water consumption to retain, transform or destroy the pollutans that can be found in soil, sediments, sludges, water, groundwater, wastewater and atmosphere (Dordio & Carvalho, 2011).

Applications of phytoremediation include sites where other remediation strategies are too expensive or impractical and the sites that have a low-level contamination and can support a treatment for long periods of time. Also, it can be used in combination with other technologies at sites that include organic, nutrient and metal pollutants that are able to be reached by the roots of chosen plants and to be sequestered, degraded, immobilized, or metabolized in place (Nabais et al., 2007).

Plants can be used to treat diverse contaminants including heavy metals, metalloids, radionuclides, salts, nutrients, xenobiotic organic chemicals, sewage, air pollutants, chlorinated pesticides, organophosphate insecticides, petroleum hydrocarbons (BTEX), polynuclear aromatic hydrocarbons (PAHs), sulfonated aromatics, phenolics, nitroaromatics, explosives, polychlorinated biphenyls (PCBs), chlorinated solvents (TCE, PCE) (McCutcheon & Schnoor, 2003; Kadukova and Kavuličova, 2011; Liu et al., 2011).

Ideal plants to be used in phytoremediation should have the following main characteristics:
- Fast growth and high biomass;
- Deep rooting;
- Harvest easily;
- Translocation and uptake capabilities (Kadukova and Kavuličova, 2011).

When trying to return a site to a state as close to the initial one, the ecological restoration of the polluted site involves the right selection of species. The requirements are to choose from the diversity of native species, instead of non-native species or monocultures (Nabais et al., 2007).

Plant species that are responsive to the uptake of contaminants are divided into four groups (Figure 1):
- Hyperaccumulators – take up very high amounts of contaminants, especially metals;
- Accumulators – take up high rates of contaminants, metals mostly;
- Indicators – take up contaminants to a degree that shows a linear relashionship to the soil level of contamination;
- Excluders – do not take up contaminants (Meuser, 2013).

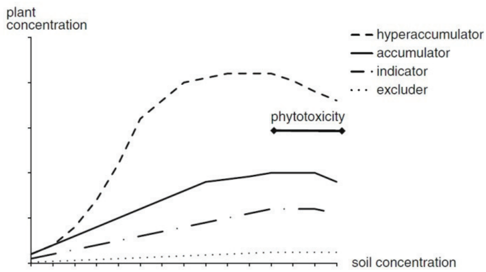

Figure 1. Plant strategies for growing in pollutted soils (Meuser, 2013)

Phytoremediation is both an in situ and ex situ technique. The focus is to accelerate the faster degradation of contaminants. The technologies that have been identified to reduce pollutants in the environment are phytoextraction, phytostabilization, phytodegradation, rhizodegradation, rhizofiltration, phytovolatilization, hydraulic control, vegetative cover, riparian corridors (Figure 2) (EPA, 2000; Dordio & Carvalho, 2011).

If the contaminant fate is regarded, the phytoremediation technologies can be sorted in: degradation, extraction, containment or a combination of these (EPA, 2000).

Phytoremediation has become in the last period a great promise of money saver and its applications can contribute with great succes at cleaning up and healing the Earth (McCutcheon & Schnoor, 2003).

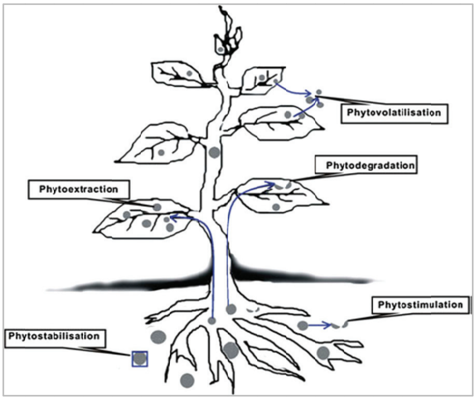

Figure 2. The main technologies of phytoremediation (Zhao et al., 2012)

RESULTS AND DISCUSSIONS

Phytoextraction

Phytoextraction is the uptake of a contaminant by plant roots and the translocation and accumulation of it in the aboveground portion of the plants. It is also called plytoaccumulation, phytoabsorbtion or phytosequestration and the process is illustrated in Figure 3. The contaminant translocation to shoots is important in order to be removed by harvesting the plants (Ali et al., 2013).
The plants used in phytoextraction should not be attractive for animals, especially mammals and birds, and they should not bring toxic elements in the food chain (Meuser, 2013).
This technique is very often used in the case of metal-contaminated soils and the extracted contaminant might be a resource (EPA, 2000).

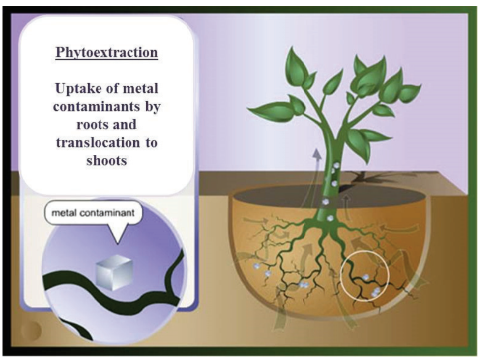

Figure 3. Phytoextraction (http://deoracle.org/learning-objects/phytoremediation-metal-contaminants.html)

Rhizofiltration

Rhizofiltration emphasizes the removal or precipitation of contaminants from an aquatic environment in the root zone. Two strategies are available in this process. One of them involves biochemical processes and removes metals by sorption and the other one is the construction of wetlands or reed beds (EPA, 2001; Kvesitadze et al., 2006).
In this technique, the plant species that are used are often raised hydroponically in greenhouses and then they are transplanted to a floating system that can be seen in figure 4, where it can be noticed that the roots are in direct contact with the contaminated water (EPA, 2001).

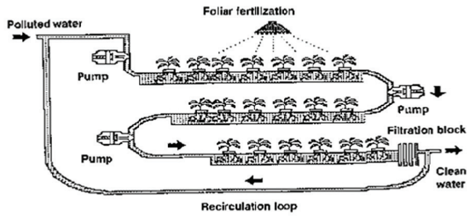

Figure 4. Rhizofiltration system (Henry, 2000)

Phytostabilization

Phytostabilization is defined as the immobilization of contaminants through sorption by roots, precipitation, complexation or metal valence reduction in rhizosphere. The plants are used to limit the mobility and bioavailability of pollutants in the environment and to prevent the contaminant migration caused by wind and water erosion and also to avoid their entry into the food chain. The process (Figure 5) is important because it stabilizes the soil matrix, minimizes erosion and the migration of sediments. It is known as phytoimmobilization and cannot be considered a permanent solution because the pollutants are not destroyed in the soil, only their movement is limited (EPA, 2000; EPA, 2001; Kvesitadze et al., 2006; Ali et al., 2013).
This technology does not ensure the cleanup of the polluted site, but it has an important contribution in preventing the further spreading of the contaminants. It mostly "polishes" less contaminated soils and composts aided by a vegetation cover (Vandenhove, 2006).

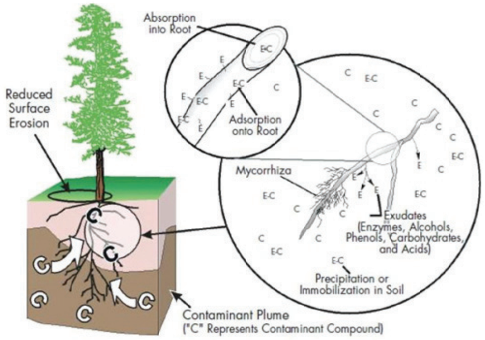

Figure 5. Phytostabilization (http://knowhowtogmo.wordpress.com/)

Rhizodegradation

Rhizodegradation is the breakdown of contaminants in soil and takes place in the rhizosphere. The microbial activity is enhanced in the root-zone and is stimulated 10-100 times higher by the secretion of exudates like sugars, amino acids, flavonoids, organic acids, sterols, carbohydrates, nucleotides, enzymes, growth factors. Due to the presence of the exudates, the number of microbial populations grows and conducts to increased contaminant biodegradation in soil. The microbial activity is stimulated because the plant roots release the exudates rich in nutrients, so the carbon and nitrogen are sources for the microbes in the soil. Rhizoremediation is called plant-assisted degradation, plant-aided in situ biodegradation, plant-assisted bioremediation and enhanced rhizosphere biodegradation (Figure 6) (EPA, 2000; EPA, 2001; Kvesitadze et al., 2006; Ali et al., 2013).

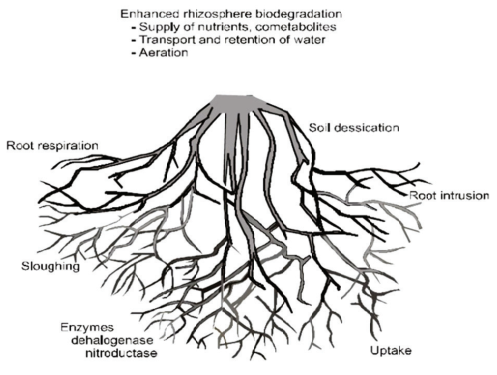

Figure 6. Rhizodegradation (EPA, 2000)

Phytodegradation

Phytodegradation is defined as the breakdown of contaminants that are uptaken by plants, followed by their degradation in plant tissues through metabolic processes. As a result of uptake, the plant stores the contaminants in cellular structures, volatizes or metabolizes them to regular metabolites, CO_2 and water. This process (Figure 7) is also known as phytotransformation and is successfully used at sites contaminated with benzene, toluene, xylene, ethylbenzene, chlorinated solvents, pesticides etc. The enzymes that aid the degradation of organic contaminants are dehalogenase and oxygenase. In the metabolic process, organic xenobiotics are accumulated and detoxified. Phytodegradation does not remove heavy metals which are nonbiodegradable (EPA, 2000; EPA, 2001; Kvesitadze et al., 2006; Ali et al., 2013).

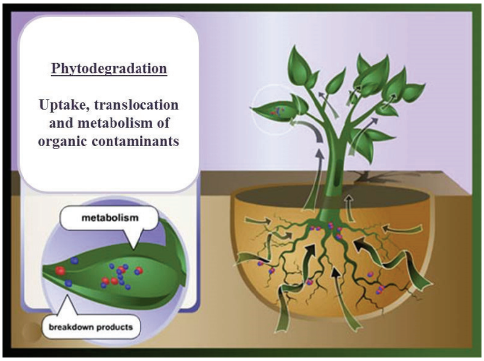

Figure 7. Phytodegradation (http://deoracle.org/learning-objects/phytoremediation-organic-contaminants.html)

Phytovolatilization

Phtovolatilization uses plants to uptake the pollutants, convert them to volatile organic compunds (VOC) and then release the contaminants or modified forms of them to the atmosphere. Because of the release, air monitoring can be required. The processes that take place are uptake, metabolism and plant transpiration. Using this technology (Figure 8) does not ensure the complete removement of contaminants and does not not eliminate VOCs from the environment, only from soil and groundwater (EPA, 2000; EPA, 2001; Kvesitadze et al., 2006, Ali et al., 2013).

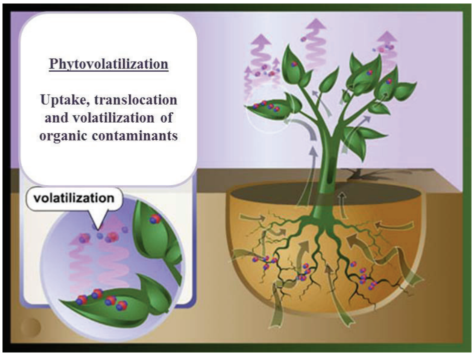

Figure 8. Phytovolatilization (http://deoracle.org/learning-objects/phytoremediation-organic-contaminants.html)

Hydraulic control

Hydraulic control is the use of plants to take up large amounts of water to contain or control the migration of contaminants in groundwater. It is also called phytohydraulics or hydraulic plume control and its mechanism involves plant transpiration that must have a high rate (Figure 9). This depends on plant species, leaf area, nutrients, climatological requirements and the activity can decrease in winter. Hydraulic control is effective within the root zone and does not need an engineered pump-and-treat system. The rooting depth of plants limit the groundwater removal (EPA, 2001).

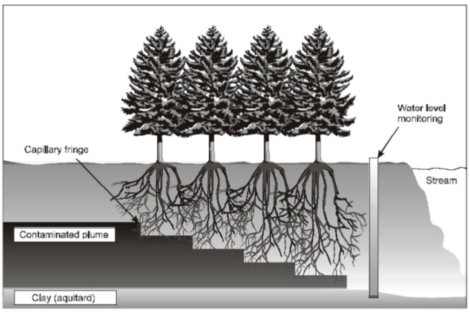

Figure 9. Hydraulic control of contaminant plume (EPA, 2000)

Vegetative cover

Vegetative covers are plants that grow in a system for a long period of time over materials that have an environmental risk. They are self-sustaining and require less maintance. Two types of vegetative covers are known: Evapotranspiration cover and Phytoremediation cover. The first one, presented in Figure 10, is a water-balance cover composed of plants and soil with the purpose of maximazing processes of plants and soil and minimazing water infiltration. The second one, illustrated in Figure 11, is also composed of soil and plants with the scope of minimazing water infiltration and to help in the degradation of underlying waste (EPA, 2000).

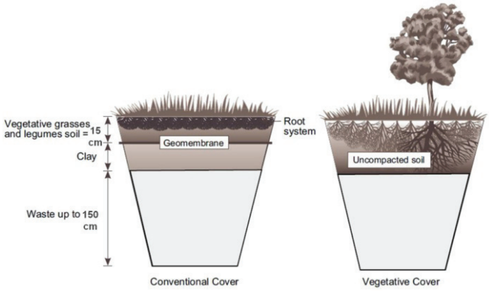

Figure 10. Evapotranspiration cover (EPA, 2000)

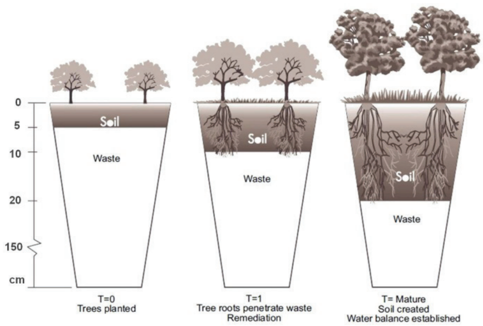

Figure 11. Evolution of the phytoremediation cover (EPA, 2000)

Riparian corridors

Riparian corridors, also known as buffer strips, are applied on river banks and watercourses to control and remediate the contamination found in groundwater and surface water (Figure 12). In the process of water treatment, the system can prevent migration and degrade contaminants in the plume. Water and contaminant uptake and plant metabolism are the mechanisms that are involved in the riparian corridors. In addition, riparian corridors provide stabilization of stream banks and prevent the erosion of soil (EPA, 2000).

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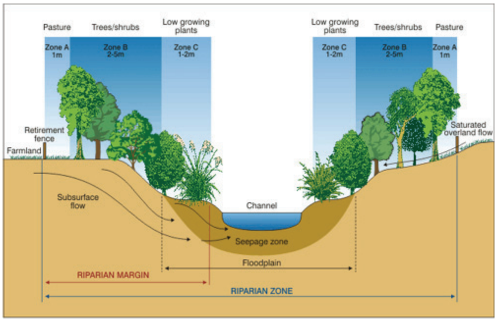

Figure 12. Riparian management (http://www.trc.govt.nz/riparian-management)

Dordio and Carvalho (2011) consider that a contaminant cannot be remediated with only one technology and the contaminant's fate is to be part of a soil-plant-atmosphere continuum. The continuum, presented in Figure 13, shows the contribution at specific points of the different phytoremediation mechanisms in the remediation process.

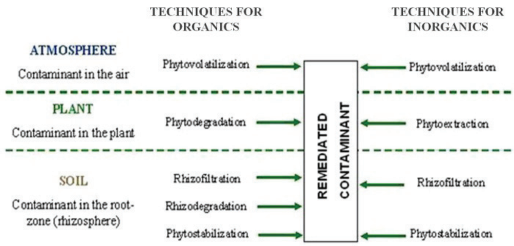

Figure 13. Contaminant fate in atmosphere, plant and soil (Dordio & Carvalho, 2011)

An overview of the phytoremediation techniques including goals, media, plants and contaminants is presented in Table 1 and the potential applications of phytoremediation as presented by McCutcheon and Schnoor (2003) is illustrated in Figure 14.

Table 1. Phytoremediation overview (EPA, 2000; Kvesitadze et al., 2006)

Technique	Process Goal	Media	Contaminants	Typical plants
Phytoextraction	Contaminant extraction and capture	Soil, sediment, sludges	Metals: Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn; Metalloids: As, Se; Radionuclides: ^{90}Sr, ^{137}Cs, ^{239}Pu, ^{238}U, ^{234}U; Nonmetals: B; Organics	Indian mustard, pennycress, alyssum, sunflowers, hybrid poplars, *Thlaspi* sp.
Rhizofiltration	Contaminant extraction and capture	Groundwater, surface water, waste water	Metals: Pb, Cd, Cu, Ni, Zn, Cr; Radionuclides: U, Cs, Sr	Sunflowers, indian mustard, water hyacinth
Phytostabilization	Contaminant containment	Soil, sediment, sludges	As, Cd, Cr, Cu, Hg, Pb, Zn	Indian mustard, hybrid poplars, grasses
Rhizodegradation	Contaminant destruction	Soil, sediment, sludges, groundwater	Organic compounds (TPH, PAHs, BTEX, pesticides, chlorinated solvents, PCP, PCBs, surfactants)	Red mulberry, grasses, hybrid poplars, cattail, rice
Phytodegradation	Contaminant destruction	Soil, sediment, sludges, groundwater, surface water	Organic compounds: chlorinated solvents, phenols, herbicides, insecticides, munitions; Inorganics: Nutrients – nitrate NO_3^-	Algae, stonewort, hybrid poplars, black willow, bald cypress
Phytovolatilization	Contaminant extraction from media and release to air	Groundwater, soil, sediment, sludges	Organics: chlorinated solvents; Inorganics: Se, Hg, and As	Poplars, alfalfa, black locust
Hydraulic control (plume control)	Contaminant degradation or containment	Groundwater, surface water, soil water	Water-soluble organics and inorganics	Hybrid poplars, willow cottonwood
Vegetative cover (evapotranspiration cover)	Contaminant containment, erosion control	Surface water, soil, sludge, sediments	Organic and inorganic compounds	Poplars, grasses
Riparian corridors (non-point source control)	Contaminant destruction	Surface water, groundwater	Water-soluble organics and inorganics: nutrient, pesticide	Poplars

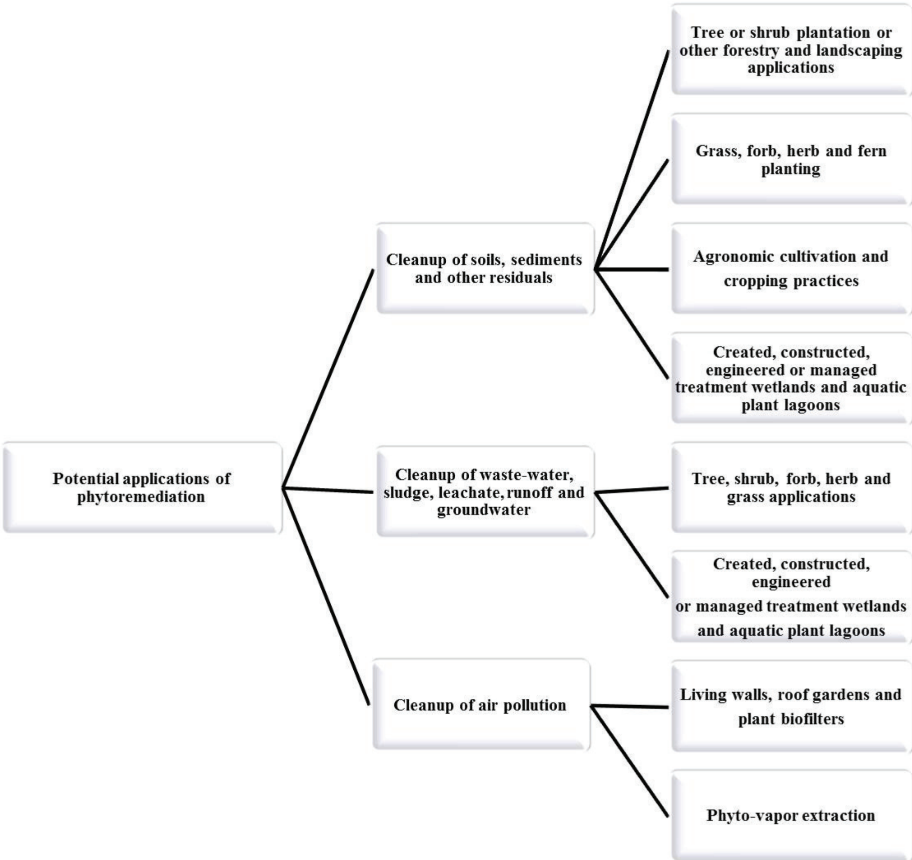

Figure 14. Potential applications of phytoremediation

DECONTAMINATION OF INDUSTRIAL SITES USING PHYTOREMEDIATION

A wide variety of sites can be decontaminated using the applications of phytoremediation. The types of sites where phytoremediation was applied or taken into consideration are: industrial and municipal landfills; pipelines; gas stations; fuel storage tank farms; military bases; army ammunition plants; mining sites; agricultural fields; wood treating sites; sewage treatment plants (EPA, 2001).

The decontamination of industrial sites for environmental benefit aims to transform post-industrial and abandoned sites into a green, aesthetically pleasing landscape. The natural habits that are created during the process give a higher value to the specific site. The regeneration of the contaminated industrial sites demands "innovative, low-cost, ecologically-sensitive and effective techniques" to clean up the environment (Dickinson, 2006).

The plants that can be used for phytoremediation applications in the industrial areas are willows, hybrid poplars that have a strong resistance to air pollution and also birches willows that are found in industrialised zones with severe air pollution (Meuser, 2013).

There are various examples of industrial sites at which phytoremediation is applied at full scale or pilot scale.

At Ashland Chemical Company tank farm in Wisconsin, US, an active industrial site, phytoremediation was required to treat petroleum products and organic solvents and to prevent contaminated groundwater from migrating. The chosen technologies were hydraulic control, phytoextraction, phytovolatilization and rhizodegradation. The used plants were hybrid poplars (EPA, 2001).

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Other examples of full scale applications of phytoremediation are: Findlay, Ohio; Laramie, Wyoming; Oneida, Tennessee; Chernobyl, Ukraine; Barje Landfill, Slovenia; Kurdjaly, Bulgaria; YPLMO, United Kingdom; Upper Silesia, Poland etc

CONCLUSIONS

The serious environmental pollution by different types of contaminants requires finding the most effective methods of remediation. The advantages that phytoremediation offers must be taken into consideration when dealing with a contaminated site. Even though it is a new technology and the research is in progress, phytoremediation seems to be a great solution for many sites because of being ecologically friendly and a green technique.

The understanding of the different types of phytoremediation techniques that are presented in this study offers the opportunity of choosing the right methods for the recovery of a site.

The contaminated industrial sites cannot be left at their actual stage, so management plans should be elaborated for their improvement and recovery and the proper types of remediation methods should be selected, phytoremediation having an important place among them.

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