Phytoremediation of Contaminated Soils-A Review

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A B S T R A C T

Phytoremediation includes phytotransformation (transformation of organic contaminants into a less toxic, less mobile, or more stable form), phytodegradation (metabolism of the organic contaminant by the plant enzymes), phytovolatilization (volatilization of organic contaminants through plant leaves), and rhizoremediation. At the soil root interface (rhizosphere), plant roots exude organic compounds that support a large and active microcosm, which leads to higher biodegradation of toxicants in the rhizosphere ecosystem. The mechanisms adopted by plants, microorganisms, and algae to interact with various types of pollutants. Phytoremediation is a cost effective and novel technology that uses plants to clean up a wider range of organic and inorganic toxicants. Plants can bioaccumulate the xenobiotics in their above ground parts, which are then harvested for removal.

Introduction

The native flora which was found in the polluted sites were efficient in removing pollutants especially metals, metalloids, pesticide residues etc., There are seven main methods and mechanisms adopted by plants, microorganisms, and algae to cope with various types of pollutants. These include (1) Rhizosphere biodegradation, (2) Phyto-stabilization, (3) Phyto-accumulation (Phyto-extraction), (4) Rhizo-filtration, (5) Phyto volatilization, (6) Phyto-degradation (Phyto-transformation), and (7) Hydraulic control.

Phyto-extraction or phyto-accumulation, in which plants absorb elements from the contaminated soil and accumulate them in various plant organs. This mechanism is often referred to as phytomining; where the plant tissues are considered mines, and harvesting of elements from plant tissues is deemed mining; (2) Phyto-stabilization, in which metals are immobilized (e.g., by adsorption and precipitation). To achieve this, plant roots release substances into the soil; these include organic matter, phosphates, and alkalizing agents. Unless properly disposed of, metals accumulated in plant tissues might negatively impact the environment and human life (e.g., via the food chain).

Pesticides

"Pesticides" is the collective term for all chemicals that are used to counteract a certain group of organisms. The primary classes of pesticides are insecticides (against insects), herbicides (against plants) and fungicides (against fungi). However, inside these different classes, there still is a wide variety between the compounds and their chemical properties. They are defined by their ionic or nonionic properties, hydrophobic properties, mechanism of action and their molecular structure (Gavrilescu, 2005). Pesticides not only cause many chronic abnormalities in human beings but may also degrade biodiversity and overall environmental quality (Benachour *et al.,* 2007). Phytoremediation encompasses many processes, such as phytotransformation (transformation of organic contaminants into a less toxic, less mobile, or more stable form), phytodegradation (metabolism of the organic contaminant by the plant enzymes), phytovolatilization (volatilization of organic contaminants through plant leaves), and rhizoremediation. At the soil-root interface (rhizosphere), plant roots exude organic compounds that support a large and active microbial population, which leads to enhanced biodegradation of contaminants in the rhizosphere.

Phytoremediation is also a cost-effective and innovative technology that uses plants to clean up a broad range of organic and inorganic wastes (Licht and Isebrands, 2005). Plants can bioaccumulate xenobiotics in their above-ground parts, which are then harvested for removal. Plants may contribute to remediation in several ways, by reducing the leaching of contaminants, aerating soil, phytodegradation/ transformation, phytovolatilization, evapotranspiration, and rhizoremediation (Chang *et al.,* 2005). Recently, molecular breeding of transgenic plants expressing enzymes responsible for phytoremediation of pesticides has begun to gain interest in the scientific community (Bode *et al.,* 2006; Chrastilova *et al.,* 2007; Novakova *et al.,* 2007).

The four main groups of insecticides are: organochlorines, organophosphates, carbamate esters and pyrethroids. When considering insecticide contamination, organochlorines are often the chemicals of greatest concern. Commonly known members of this group are the DDT (dichlorodiphenyl-trichloroethane), DDE (dichlorodiphenyl-dichloroethylene), DDD (dichlorodiphenyl-dichloroethane), the HCHs (hexacyclochloro-hexanes: a, b, g, d, t) and chlordane (Pascal Lorber and Laurent, 2011). The behaviour of pesticides in the environment is influenced by a combination of natural processes. When in the environment, pesticides interact with soils, water and organisms and the interactions are controlled by a complex collection of biological, physical and chemical reactions

The most widespread herbicide contamination occurs with atrazine (Pascal Lorber & Laurent, 2011). Atrazine (2-chloro-4-(aminoethyl) -6- (aminoisopropyl)-s-1,3,5-

triazine) is a photosynthesis-inhibiting herbicide and is used in agriculture for the control of annual grasses and broad-leaved weeds, as well as in industrial sites and along railroads (Garmouna *et al.,* 1998). This caused widespread contamination of surface and groundwater reservoirs. Atrazine is known to be an endocrine disruptor, and significant toxicity has been noted in amphibians (Forson and Storfer, 2006).

DDTs strongly adsorb to soil particles, further enhanced by alternate drying and wetting. Due to their hydrophobic and lipophilic nature, DDTs naturally accumulate in adipose tissue and often get magnified in the food chain. Several higher trophic level animals have been shown to experience deleterious effects of DDT exposure, e.g., egg shell thinning in birds and endocrine disruptors in mammals (Sharpe, 1995). The most important contaminants are hexachlorobenzene (HCB) and pentachlorophenol. HCB is a hydrophobic organic compound that is known for its bioaccumulation and the analyte has been detected in air, soil, fish, birds and even human milk (Qiu *et al.,* 2004).

The processes that influence pesticide contamination can be classified into three types: (1) transport processes, which move the pesticide from the original point of introduction, (2) transfer processes that control the pesticides movement through environmental compartments such as water, sediments, the atmosphere and biota and (3) transformation processes that change the structure/nature of a pesticide or even completely degrade it to its constituent elements.

Pesticide transformation or degradation is the oxidation of pesticide molecules. When a pesticide is introduced into the environment, it is prone to different transformation pathways. First, there is a chemical degradation, where the analytes react with organisms or enzymes in the environment and degradation occurs. Secondly, the molecules can be degraded by exposure to light; photodegradation. Thirdly, microbial degradation can occur in both bulk and rhizosphere soil.

Phytoremediation is also to be considered to be an innovative, cost-effective and ecologically beneficial technology (Hussain *et al.,* 2009). Phytoremediation is a collection of processes, including phytotransformation, phytodegradation, phytovolatilization and rhizoremediation. For the first three processes, uptake of the contaminant into the plant tissues is necessary; rhizoremediation takes place at the soil-root interface or rhizosphere. All of the above-mentioned phytoremediation processes can be influenced by plant-associated microorganisms. Both rhizospheric and endophytic microorganisms can play a role in the remediation through pesticide degrading and plant growth promoting capacities (Glick, 2003).

The degradation of pesticides is often greater in rhizosphere soil than it is in bulk soil. This can be explained by a phenomenon known as the rhizosphere effect. The presence of microbial communities in the soil can be beneficial to the plant by producing protective or beneficial compounds such as 1-aminocyclopropane-1-carboxylate (ACC) deaminase. ACC is the precursor molecule for ethylene, which is a stress hormone that plants often produce in contaminated soils. ACC deaminase degrades ACC, ethylene levels are lowered and the plants experience less stress from contaminant exposure. All of these mechanisms can decrease plant phytotoxicity, increase plant growth and increase phytoremediation potential.

Plant root systems can excrete enzymes that degrade pesticides in the rhizosphere, but they

also release photosynthetic products that can serve as nutrients for rhizospheric bacteria. Kidd, Prieto-Fern_andez, Monterroso, and Acea (2008) showed a higher dissipation of HCHs in the rhizosphere when *Cytisus striatus* and *Holcus lanatus* were inoculated with HCH degrading bacteria. Ahmad *et al.,* (2012) reported a 50% increase in chlorpyrifos degradation in the *Lolium multiflorum* rhizosphere when the plant roots were inoculated with *Bacillus pumilus C2A1*. The successful degradation of phoxim when carrot (*Daucus carota*) and green onion (*Allium fistulosum*) were inoculated with the *arbuscular mycorrhizal* fungi *Glomus intraradices* and *Glomus mosseae*; notably, contaminant degradation was negligible in noninoculated plants. The fungus Trichoderma harzianum was isolated from a marine plant *Didemnum ligulum* and had the capacity to degrade 50 mg/L phoxim in liquid medium in 7 days (Vacondio *et al.,* 2015). The scientists conducted a large experiment on pesticide degradation by fungi. These researchers tested 17 white rot fungi; 16 were able to degrade the pesticides parathion, terbufos, azinphos-methyl, phosmet and tribufos after a four day growth period.

Phillips *et al.,* (2006) reviewed the degradation of HCH in soil and reported many research findings that showed a degradation of HCH isomers under anoxic environment. Temperature and pH are the major factors affecting the biodegradation of pesticides in soil (Arshad *et al.,* 2007). Temperature not only affects the rates of biochemical reactions, as all microbial activities depend on thermodynamics, but also has a direct impact on cell physiology-altering proteins and cell membrane permeability. A temperature range of 15 to 40∘C was considered favorable for the degradation of pesticides by isolated pesticide-degrading bacteria.

In soil, the main source of organic matter that provides nutrients is crop residues. The application of wheat residue-derived char released nutrients and stimulated microbial growth and degradation of pesticide (benzonitrile) in soil. Phosphorus was primarily responsible for stimulation and degradation. Slow degradation of benzonitrile after its 88% degradation was attributed to adsorption on char. Organic matter characteristics (i.e., aromaticity) can vary among the organic fractions and may lead to differences in sorption capacity (Ding *et al.,* 2002). Also, different groups of pesticides behave differently in soils. Boivin *et al.,* (2005) correlated adsorption of non-acidic pesticides (atrazine, isoproturon, and trifluralin) to soil organic matter content. Singh *et al.,* (2006) studied the biodegradation of organophosphate pesticides (fenamifos and chlorpyrifos) and did not find any impact of soil organic matter on the pesticide biodegradation rates. In another study, Fenlon *et al.,* (2007) found that diazinon (organophosphate pesticide) only appreciably mineralized in two of the organic soils when assessed in organically and conventionally managed soils compared to cypermethrin (pyrethroid), which degraded significantly in all the investigated soils. This contrasts with earlier reports where high organic matter reduced biodegradation by reducing the bioavailability of compounds to degrading microorganisms, especially when the compounds have high Koc value (Karpouzas *et al.,* 2000).

The uptake of pesticides by plants is governed by numerous soil and plant characteristics. Soil factors that influence the availability of pesticides in soil for either microbial degradation or plant uptake. In addition to moisture content, organic carbon, and clay content in soil, pesticide residence time in the soil can also affect its availability for transport and plant uptake. Sorption

desorption of two sulfonylaminocarbonyl-triazolinone herbicides in clay loam and loamy sand soils. In both soils, 12 weeks of incubations increased sorption (*Kd*) by a factor of 5 to 7. The uptake of pesticides varies among different plants. The uptake of pesticides (atrazine and lambda-cyhalothrin) from water by two different plants (*Juncus effusus* and *Ludwigia peploides*) under hydroponic conditions. Higher atrazine uptake was measured in *J. effuses,* and higher lambda-cyhalothrin uptake occurred in *L. peploides*. Atrazine was translocated to upper plant biomass in macrophytes, while 98.2% of lambda-cyhalothrin was sequested in roots of *L. peploides*, of which 25.4% was translocated to upper plant biomass. The removal of pesticides from soil by plants also relies on pesticide type. The tendency of a pesticide to partition from water into organic phase (*Kow*) controls its bioavailability and translocation in plant (Bromilow & Chamberlain, 1995). Twelve non-ionized pesticides with different physicochemical properties were studied by Carvalho *et al.,* (2007). The uptake of pesticides by roots and shoots of an aquatic plant, parrot feather (*Myriophyllum aquaticum*). Root concentration factor (RCF) and submerged shoot concentration factor (SSCF) increased with increasing *Kow* of the pesticide. In an uptake study of hydrophobic organochlorine pesticides (OCPs) in vegetables, Gonzalez *et al.,* (2005) observed that vegetables accumulated OCPs efficiently with tissue residues 4- to 45-fold greater than those of soils, and OCP distribution in tissue was found to be *Kow*-dependent.

Apart from soil and pesticide properties, pesticides undergo chemical or biological transformations in water and soil environments and form metabolites, which are often weak electrolytes and may be readily taken up by plants (Trapp, 2000). In an environment contaminated with multifarious pollutants, the presence of heavy metals can affect the uptake of pesticides by plants. Su *et al.,* (2005) revealed that the interaction between cadmium (Cd^{2+}) and atrazine reduced the individual toxicities to rice seedlings. The addition of equimolar concentrations of Cd^{2+} and atrazine in a solution increased the bioconcentration factor (BCF) of atrazine in roots and shoots of rice seedlings. Though soil-to-plant is a major route of pesticides uptake, plants can also absorb airborne pesticides. Lee *et al.,* (2003) conducted a study using the insecticide chlordane and reported significantly different compositional profiles of chlordane components in zucchini (*Cucurbita pepo* L.) plant tissues exposed to airborne and soil chlordane in parallel studies, which suggested two distinct plant uptake routes for the insecticide. Grangeot *et al.,* (2006) studied the spray retention, foliar uptake, and translocation of glufosinate and glyphosate in *Ambrosia artemisiifolia*. Their results indicated that glufosinate was readily taken up (maximum; >80% of the applied label) by *A. artemisiifolia* leaves, with half of the maximum uptake being reached within 6 h. The foliar uptake of glyphosate was nearly complete, and half of it was attained in 3 h. Glufosinate and glyphosate were ambimobile, and their translocation out of the treated leaves amounted to 13–16% and 11– 15%, respectively, of the absorbed radioactivity. After uptake, glufosinate was mainly distributed in the apical developing tissues, while glyphosate was distributed in apical developing tissues as well as roots.

Xia and Ma (2006) revealed that water hyacinth (*Eichhonia crassipes*) removed ethion, an organophosphorus insecticide, from water and degraded the pesticide within the plant. Similarly, poplar cuttings could take up atrazine and hydrolyze and dealkylate it to less toxic metabolites in roots, stems, and leaves (Chang *et al.,* 2005). In another study,

dehalogenation of DDT was observed in aquatic plant elodea (*Elodea canadensis*) (Garrison *et al.,* 2000). The primary transformation reactions (phase I) within plants are catalyzed by induced endogenous enzymes that attack common functional groups of pesticides like NO_2^-, NH_2^-, OH^-, $COOH^-$ or Cl^-, Br^-, and I^- by oxidation, reduction, or hydrolysis reactions. Conjugation takes place by the addition of a sugar moiety or tripeptide like glutathione to the contaminant or a newly transformed product. In most cases, glutathione (GSH) forms conjugates with various xenobiotics such as pesticides by nucleophilic addition reactions catalyzed by glutathione-*S*-transferase (GST) (Edwards *et al.,* 2000). The expression of GST encoding genes is induced by many xenobiotics such as pesticides. pesticides that undergo conjugation with glutathione are atrazine, simazine, and cyanazine, while 2,4-D, chloramben, and bentazon prefer conjugation with glucose. Conjugates formed by either method are less toxic due to having more water solubility than the parent compound and are sequestered into the vacuole where they can be further degraded (Edwards *et al.,* 2000; Foyer & Noctor, 2001). Conjugated compounds require adenosine triphosphate (ATP)-dependent enzymes to move into the vacuole, and their transport across the vacuole has been demonstrated in many plant species. Enzymes that catalyze the entry of glutathione and glycosyl-derivatives are glutathione and glucoside-conjugate transporters, respectively. ATP-binding cassette (ABC) transporters are the best-characterized system for transferring pesticides out of root cells and into vacuoles after conjugation by GSTs. During metabolic processes, insoluble conjugates with cell wall components are also formed in plants either by nonselective reactions with free radicals used in lignin synthesis or by more selective incorporation into hemicelluloses. In phase III, plant metabolism is confined to compartmentation and storage. Unlike mammals, plants do not possess a way to excrete unwanted compounds. Soluble metabolites are stored in the vacuole or become part of cell wall material. Davis and Erickson (2002) reviewed the potential for volatization of fumigants ethylene dibromide, ethylene dichloride, and carbon tetrachloride. Field studies in Florida and Utah revealed trichloroethylene (TCE) uptake by all exposed plants at both sites, but TCE concentration in plant was 10–100 times higher at the Utah site. TCE could only be identified in transpiration samples collected at the Utah site. The lack of phytovolatilization and significantly lower TCE plant concentrations at the Florida site were most likely due to the smaller fraction of contaminated groundwater used by plants for transpiration because of the frequent precipitation (Doucette *et al.,* 2003).

The term *rhizosphere* describes the soil volume around plant roots, which is influenced by the activities of the living roots. Rhizosphere is a complex environment that supports a huge number of metabolically active microbial populations, several orders of magnitude higher than the non-rhizospheric soil (Capdevila *et al.,* 2004). Rhizo-remediation significantly depends upon the type of relevant gene pool in the rhizosphere for a particular pesticide. Moreover, exchanges in genetic makeup of rhizosphere caused by foreign gene in terms of horizontal gene transfer among microbial communities may be helpful to maximizing the rhizodegradation of pesticides. Studies have described the horizontal gene transfer of degradative genes from foreign bacteria to indegeneuos soil bacteria, which may enable indegeneuos soil microorganisms to degrade pesticides in the soil environment. The horizontal transfer of organophosphorus pesticide hydrolase gene cluster and methylcarbamate degrading *mcd* gene (Desait

et al., 2003) in microbial populations in soil. de Lipthay *et al.,* (2001) showed that horizontal transfer of 2,4-dichlorophenoxyacetic acid/2-oxoglutarate dioxygenase encoding gene *tfd*A to phenol-degrading strains significantly enhanced the degradation rate of phenoxyacetic acid in sterile and non-sterile soil microcosms. These results strongly acknowledge that inoculation of plants with microbes containing catabolic plasmid could be helpful in their dissemination among microbial species to degrade xenobiotic compounds in the rhizosphere. Bacterial diversities belonged to actinobacteria*,* bacteroidetes, and proteobacteria. The major dominant families were highly similar to *Variovorax paradoxus, Burkholderia cepacia, Arthrobacter* sp., and *Bosea* sp. Though various atrazine-degrading gene compositions were observed, two of these are *atz*ABCDEF, *trz*ND and *atz*BCDEF, *trz*N were largely dominant. The first was dominant in bacterial communities isolated from the maize rhizosphere, while the second was dominant in bacterial communities isolated from bulk soil. According to the results obtained, maize rhizosphere imparted a significant impact on the genetic structure, diversity, and pesticides degrading gene composition.

Sonoki *et al.,* (2005) introduced an extracellular fungal enzyme, the laccase of *Coriolus versicolor*, into tobacco plants. The transgenic plant was able to remove pentachlorophenol by producing laccase and secreting into the rhizosphere. Similarly, for the decontamination of organophosphorus pesticide, Wang *et al.,* (2008) expressed a bacterial organophosphorus hydrolase (OPH) gene in tobacco plants. The transgenic plants degraded more than 99% of methylparathion after 14 days of growth. A variety of plant enzymes, including peroxygenases, cytochrome P450, peroxidase, glutathione-*S*-transferases, carboxylesterases, *N-*, *O*glucosyltransferases and *N-*, *O-*

malonyltransferases, are involved in the phytotransformation of xenobiotics in plant cells (Wolfe and Hoehamer, 2003). Glutathione *S*-transferases are a multigene family of detoxifying enzymes for herbicides. The gene *gstI–6His* from maize, which encodes for 6His-tagged GST I, was used for the construction of a binary vector suitable for genetic engineering of tobacco plants (*Nicotiana tabacum*).

Peuke and Rennenberg (2005b) used transgenic poplars with enhanced GSH synthesis in a greenhouse experiments and revealed that transgenic poplars showed a high potential for uptake and detoxification of heavy metals and pesticides. GSH is synthesized in two ATP-dependent steps catalyzed by α- glutamylcysteine synthetase (γ -ECS) and glutathione synthetase (GSHS). Shiota *et al.,* (1994) first reported the enhanced resistance of transgenic tobacco (*Nicotiana tabacum cv. Xanthi*) plants toward herbicide chlortoluron, expressing a genetically engineered fused enzyme between rat cytochrome P4501A1 (CYP1A1) and yeast NADPH-cytochrome P450 oxidoreductase. In these plants, microsomal monooxygenase activities were approximately 10 times higher toward both 7-ethoxycoumarin and benzopyrene than in the control plant (non-transgenic plants). Shiota *et al.,* (1996) reported that transgenic tobacco plants expressing the genetically engineered fused enzyme between rat cytochrome P4501Al and yeast NADPH-cytochrome P450 oxidoreductase were resistant to chlortoluron at concentrations of 10 to 50 μM in Murashige and Skoog medium, but herbicide concentration up to 10 μM was toxic to control plants. Inui *et al.,* (2001) investigated the metabolism of 50 herbicides and 7 other chemicals with different structures and modes of action in the microcosms by recombinant yeast strains expressing each of 11 human P450 species. Of these, 27 herbicides and 6 other chemicals

were mainly metabolized by *CYP1A1, CYP1A2, CYP2B6, CYP2C9, CYP2C18, CYP2C19, CYP2D6,* and *CYP3A4* genes. Afterward, on the basis of these results, they developed transgenic potato plants T1977 expressing and co-expressing three major P450 species *CYP1A1, CYP2B6,* and *CYP2C19*. These plants exhibited crosstolerance toward the herbicides acetochlor, atrazine, chlortoluron, methabenzthiazuron, metolachlor, norflurazon, and pyributicarb, and demonstrated a higher activity in the metabolism of each of chlortoluron, atrazine, pyributicarb, and methoxychlor than non-transgenic control plants.

Yamada *et al.,* (2002a, 2002b) first integrated a rat cytochrome P450 gene (*CYP1A1*) under the control of patatin promoter into potato to enhance tuber-specific expression. They developed a total of 106 transgenic plants PAT1A1 that demonstrated higher activity of monooxygenase in the leaves than the non-transgenic plants, when treated with 10% exogenous sucrose due to the patatin promoter containing the sucrose-inducted elements. Then, they selected one representative plant (Ag2197) on the basis of monooxygenase activity in the leaves. The amount of residual herbicides was much less in Ag2197 plants than non-transgenic plant. Kawahigashi *et al.,* (2003) introduced a human cytochrome P450 gene, *CYP1A1*, into rice plants (*Oryza sativa cv.* Nipponbare) to induce herbicide tolerance in rice plants

Heavy metals

Heavy metals are a group of 53 elements with density higher than 5 g/cm^3 Although some metals are essential for plant and animals, many are toxic at high concentrations. Trace elements like iron (Fe), copper (Cu), nickel (Ni), zinc (Zn), and manganese (Mn) are essential for normal growth and development of plants and are required in electron transfer,

in numerous enzyme catalyzed or redox reactions, and have structural function in nucleic acids. Others like Cu and Zn are involved in plant growth, flowering, and seed production, especially when their availability is very low (Vamerali *et al.,* 2010).

In European Union, contamination by metals accounts for >37% of the cases, followed by mineral oil (33.7%), polycyclic aromatic hydrocarbons (13.3%), and others (Vamerali *et al.,* 2010). In uncontaminated soils, heavy metal concentrations vary in magnitudes, but on average, the order of metal concentrations is: Cd 0.1– 0.5 ppm, Zn 80 ppm, and Pb 15 ppm. However, in polluted soil, the concentrations were: Cd >14,000 ppm, Zn >20,000 ppm, and Pb >7,000 ppm (Gohre and Paszkowski 2006). Contamination is often highly localized in industrialized countries, and hence, the pressure to use contaminated land and water for food production or for human consumption is minimal. According to their distinct chemical and physical properties, three different molecular mechanisms of heavy metal toxicity are recognized: (1) production of reactive oxygen species by autoxidation and Fenton reaction (Fe, Cu), (2) blocking of essential functional groups in biomolecules (Cd, Hg), and (3) displacement of essential metal ions from biomolecules (Schutzendubel and Polle 2002). Phytotoxicity is mainly associated with nonessential metals like Cd, As, Cr, and Pb, which generally have very low toxicity thresholds and lower values for hyperaccumulation (especially for Cd) than the other metals (Vamerali *et al.,* 2010). At elevated concentrations, heavy metals interfere with essential enzymatic activities by modifying protein structure or by replacing a vital element resulting in deficiency symptoms. Phytostabilization and phytoextraction are the most reliable categories of phytoremediation for heavy metals (Gohre and Paszkowski, 2006).

Phytostabilization is used to provide a cover of vegetation for a moderately to heavily contaminated site to prevent wind and water erosion. It is often performed using species from plant communities growing on local contaminated sites. These plants possess tolerance to the contaminant metals, develop an extensive root system, provide good soil cover, and ideally immobilize the contaminants in the rhizosphere. Plants most suitable for phytoextraction are able to hyperaccumulate contaminants, possess tolerance to these chemicals, have a high biomass, and have a short growing cycle (Cho *et al.,* 2009).

Weissenhorn *et al.,* (1995a, b) observed high levels of mycorrhizal colonization in agricultural soils contaminated with metals originating from smelter and sludge amendments. In ultramafic soils in South Africa, naturally occurring Ni-hyperaccumulating plants of the Asteraceae were heavily colonized by AM-fungi. Weissenhorn *et al.,* (1995a) observed no correlation between AM abundance in maize (*Zea mays*) and the degree of metal (Cd, Ni, Zn, Cu, Pb, and Mn) pollution in a field trial. On the other hand, mycorrhizal colonization and growth of external hyphae were inhibited by sewage sludge-contaminated soil containing Pb, Zn, and Cd (Del Val *et al.,* (1999). Tonin *et al.,* (2001) found that Cd- and Zn-polluted soil enhanced mycorrhizal diversity index of clover (*Trifolium repens* L.) roots. Similarly, Turnau *et al.,* (1996) reported that metal-tolerant *Oxalis acetosella* L. plants colonizing acid forest soils treated with Cd, Zn, and Pb containing industrial dust showed higher AM colonization than non treated soils.

Trace elements (TE) such as As, Cu, Cr, and Zn can be in excess in contaminated soils at wood preservation sites, especially when Cu-based salts, i.e. Cu sulphate and chromate copper arsenate (CCA), have been long term used as preservatives against insects and fungi, which may result in soil phytotoxicity (Kumpiene *et al.,* 2008). Among the feasible remediation options, phytostabilisation, singly and in combination with mineral and organic amendments (i.e. aided phytostabilisation), is a less invasive, low-cost phytotechnology able to restore (1) the physical and chemical properties of TE contaminated soils and (2) the cascade of biological processes and functions leading to remediated ecosystem services (Bolan *et al.,* 2014; Kumpiene *et al.,* 2008). Crude oil is rich in heavy metals such as Cd, Cr, Cu, Ni, Pb, V, Zn, etc. (Wake, 2005), while other heavy metals are associated with crude gas (Hg and As).

In situ (phyto) stabilisation techniques aim at decreasing both the labile TE pool and providing nutrient supply, and simultaneously promoting other beneficial process such as water retention, by incorporating organic and mineral amendments (Hattab *et al.,* 2014). These techniques are able to enhance one or several processes such as metal adsorption through increased surface charge, formation of organic and inorganic metal complexes, sorption on Fe, Mn, and Al oxides, and precipitation (*Kumpiene et al.,* 2008).

Glomalin, an insoluble glycoprotein, is produced abundantly and released by AM fungi and plays a critical role in soil stability. Glomalin also binds to heavy metals in the soil and can be extracted from soil together with a significant amount of bound heavy metals. Gonzalez-Chavez *et al.,* (2004) reported that up to 0.08 mg Cd, 4.3 mg Cu, and 1.12 mg Pb per gram glomalin could be extracted from polluted soils that were inoculated with laboratory cultures of AM-fungi. Moreover, glomalin from hyphae of an isolate of *Gigaspora rosea* sequestered up to 28 mg Cu g-1 in vitro. Similarly, Bedini *et al.,* (2010) reported that the amount of Cu, Ni, Pb, and Co bound to glomalin was 2.3, 0.83, 0.24, 0.24%, respectively, of the total content

of heavy metals. Fungal cell wall is made up of chitin that has an important metal-binding capacity. And therefore, this binding ability of chitin is likely to reduce the concentration of heavy metals in soil. Mycorrhizal fungi improve phytoextraction by making metals more available for uptake by plants. Improved phytoextraction following mycorrhization may be achieved by several mechanisms like (1) better plant growth and biomass production, (2) increased plant tolerance to metals, and (3) greater metal concentrations in plant tissues (Vamerali *et al.,* 2010). *Pteris vittata* L. (Chinese brake fern) was the first reported of the eight As hyperaccumulator plant species identified so far. It has been found to accumulate As in its fronds with extraordinary efficiency, primarily due to high translocation from roots to shoots and to effective detoxification mechanisms within the plant. Low to moderate (4.2–12.8%) levels of AM colonization have been observed in *P. vittata* growing at several As-contaminated sites. The non-AM *P. vittata* plants accumulated 60.4 mg As per kg while plants colonized by AM-fungi isolated from an As mine accumulated 88.1 g As per kg accompanied by enhanced growth. Phosphate uptake was 36.3 mg per pot in non-colonized and 257 mg per pot in colonized plants. AM-fungi are likely to have a strong influence on arsenate uptake due to their role in enhancing phosphate acquisition for the host plants. Mycorrhizal hyphae and plants can modify plant uptake of As by means of changes in the biotransformation of As at the interface between roots and rhizosphere soil (Ultra *et al.,* 2007), downregulation of arsenate or phosphate transporters in the epidermis and root hairs (Gonzalez-Chavez *et al.,* 2002), retention of As in external mycelium and/or possibly increased efflux of As as arsenite from mycorrhizal roots (Wang *et al.,* 2008), and alteration of the translocation of As from roots to shoots. Arbuscular mycorrhizal fungi can also induce the accumulation of other

heavy in host roots. *Berkheya coddii* Roessler, a Ni-hyperaccumulator plant of family Asteraceae, for example is used for phytomining, that is, for the recovery of metals from plant tissues (Salt *et al.,* 1998).

Among higher plants, poplars and perennial grasses possess a strong phytostabilisation capability (Marmiroli *et al.,* 2011). The immobilization of TE in soil can also be induced through the use of soil amendments that reduce TE mobility and bioavailability (Hooda 2010). Several mineral and organic amendments such as lime, coal fly ashes, phosphates, red muds, compost, biosolids, iron grit and Fe or Mn or Al oxides can improve phytostabilisation and production of plant-based feedstock through decrease in TE bioavailability (Kumpiene *et al.,* 2008). The arylamine *N*-acetyltransferases (NAT) are xenobiotic-metabolizing enzymes that catalyze the transfer of an acetyl group from acetyl CoA (AcCoA) to the nitrogen or oxygen atom of arylamine based xenobiotics and their hydroxylated metabolites. They play an important role in the detoxification of many xenobiotics and pesticides.

In conclusion this review paper provides wider conceptual as well as experimental methodologies for removing contaminants in the ecosystem by plants, microorganism, algae etc., due to increasing population and industrialization the entire world is contaminated with different types of pollution and its impact on environment is very serious that encounter immeasurable problems to living forms. To solve the problem by enhancing the green belt by afforestation or encourage the native plant species conservation to remove the toxicants in the environment.

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