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# Phytoremediation of Heavy Metals and Persistent Organic Pollutants (POPs): A Review

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## ABSTRACT

Phytoremediation is an innovative and progressive technology that uses plants to rid soil, groundwater, air, sediments, and surface water of contaminants. This paper presents the status of phytoremediation technologies with specific emphasis on phytoremediation of heavy metals and persistent organic pollutants (POPs). Soil microorganisms can degrade organic contaminants, but not the POPs, while heavy metals usually require immobilisation or removal. Most of the conventional remedial technologies are costly to implement and pose further damage to the soil, thus subsequently causing negative impacts on the ecosystem. Although phytoremediation technique, among other limitations, can be time-consuming process, it is eco-friendly and cost-effective technique, and this underscores its comparative advantage over the conventional technique. Among the several phytoremediation techniques, phytodegradation is most effective with organic contaminants, including the POPs, while phytoextraction and phytostabilisation are best with inorganic pollutants. Phytovolatilization and rhizofiltration are effective with inorganic and organic contaminants. Collectively, these processes are able to isolate, destroy, transport, and remove organic and inorganic pollutants from contaminated media.

## INTRODUCTION

The phenomenal rise in urbanisation, coupled with the modern agricultural systems throughout the world, has contributed immensely to generation of contaminants in the environment. The major concern due to disposal of industrial and urban wastes generated by human activities is the contamination of soil (Gosh and Singh, 2005). Waters become polluted by natural as well as anthropogenic activities; natural sources include soil erosion, urban runoff and volcanic activities, while human factors include textile industries, electroplating, nuclear power plant, refining and many other factors (Akpor *et al*., 2014). Major components of inorganic contaminants are heavy metals (Adriano, 1986; Alloway, 1990). Metals need immobilisation or physical removal. Soil microorganisms can degrade organic contaminants, except the Persistent Organic Pollutants (POPs). Although many metals are essential, all metals are toxic at higher concentrations, because they cause oxidative stress by formation of free radicals. Thus, metals render the land unsuitable for plant growth and disrupt the biodiversity. Another reason why metals may be toxic is that they can replace essential metals in pigments or enzymes, disrupting their functions (Henry, 2000).

Albeit several control measures have been devised to mitigate or restrict the release of contaminants in the soil and water, they are not sufficient for checking the contamination. Before the arrival of plant-based remediation, conventional remediation techniques have been applied in environmental processes; metal contaminated soil can be remedied by chemical, physical and biological techniques. Most of the conventional remediation techniques are costly to implement and cause further disturbance to the already damaged environment (Mench *et al*., 1990; Alloway and Jackson, 1991). The physicochemical techniques for soil remediation render the land useless for plant growth as they remove all biological activities, including useful microbes such as nitrogen-fixing bacteria, mycorrhiza, fungi, as well as fauna in the process of decontamination (Bruns *et al*., 1996).

Alternative technology of hazardous substance removal should be concerned about cost-effective and eco-friendly techniques. The integration of plant in containment of heavy metals and organic contaminants in the soil and water has been dependable as it eco-friendly and cost-effective. The idea of using metal accumulating plants to remove heavy metals and other compounds was first introduced in 1983, but the concept has actually been implemented for the past 300 years (Henry, 2000). Plant-based bioremediation technologies have been collectively termed phytoremediation. The generic term ‘phytoremediation’ consists the Greek prefix *phyto* (plant), attached to the Latin root *remedium* (to correct or remove an evil) (Cunningham *et al*., 1996). This refers to the use of green plants and their associated microbiota for the in-situ treatment of contaminated soil and groundwater (Sadowsky, 1999). This technology can be applied to both organic and inorganic pollutants present in soil, water or the air (Salt *et al*., 1998; Raskin *et al*., 1994).

This paper focuses studies on the mechanisms of phytoremediation of heavy metals and organic pollutants, especially the POPs, using in-situ technique. It also reports about the hyperaccumulators’ response to presence of soil heavy metals. The paper also gives insights into the works done by authors to improve on genetic engineering in plants for improved phytoremediation.

## Brief history of phytoremediation

While phytotechnologies have gained attention over the last several years, the processes have been taking place naturally for over three centuries. Throughout the 1970s and the following decades, plants were heavily tested and used to treat soil infiltrated with metals and contaminants in wetlands. As a result, techniques for these uses are well established (McCutcheon *et al*., 2003). Widespread use of phytoremediation by federal and state governments, as well as non-governmental organizations, began in the 1980s (EPA, 2005b). The use of the term phytoremediation was initiated by the Environmental Protection Agency (EPA) in 1991, and it was first used in open technical literature in 1993 by Cunningham and Berti. In the late 1990s, new uses for phytoremediation were discovered, and it became known among innovative scientific technologies (McCutcheon *et al*., 2003). Phytoremediation was derived from other fields such as agronomy, forestry, chemical and agricultural engineering, microbiology, and many others. Since its inception, it has developed into an independent field of study and a widely applicable technology (Tsao, 2003). Bench-, pilot-, and field-scale research continues to provide information and insight for future exploration and application.

## Heavy metals

Any metal that cannot be degraded biologically and causes many environmental problems is called heavy metal. Heavy metals are elements having atomic weight between 63.54 and 200.5g and a specific gravity greater than 4 (Kennish, 1992). Heavy metals occur as natural constituents of earth crust. It is well known that heavy metals cannot be chemically degraded and need to be physically removed or be transferred into nontoxic compounds (Gaur and Adholeya, 2004). To reduce the heavy metals toxicity and their removal from contaminated soil is important for protection of environment (Duruibe, 2007). From fertilizer and industrial wastes, heavy metals enter into the environments which threaten nature, because they accumulate at high levels.  Migration of these contaminants into noncontaminated areas as dust or leachates through the soil and spreading of heavy metals containing sewage sludge are a few examples of events contributing towards contamination of the ecosystems (Gaur and Adholeya, 2004).  Heavy metal pollution has become a global problem. Approximately 20 metals are considered toxic which threaten the human health (Bibi *et al*, 2016). Zinc (Zn), lead (Pb), cobalt (Co), cadmium (Ca), iron (Fe) and chromium (Cr) are most common heavy metals which are toxic even at low concentrations and abundantly present in the wastewater (Singh *et al*., 2012). Heavy metals enter into the human body through direct ingestion of soil, using vegetables grown in contaminated soil and dust inhalation (Roozbahani *et al*., 2015).

## Persistent organic pollutants (POPs)

POPs are the organic compounds that are resistant to environmental degradation through chemical, biological, and photolytic processes (Russell, 2005). Many POPs, such as Poly Chlorinated Biphenyls (PCBs) and Organochlorine Pesticides (OCPs) also had undesirable outcomes. The chemicals were found to bioaccumulate in the food-chain (Reijnders, 1980; Tanabe *et al*., 1983) because of their resistance to biodegradation (recalcitrance) and high lipophilicity (Niimi, 1987; Mackay *et al*., 1992b). This, in turn, spreads the chemical to new regions where more animals, in which it will bioaccumulate, can be exposed. These ripple effects can lead to extensive damage in the environment and health.

International attention was commanded by characteristics that make POPs a global threat: toxicity, persistence, bioaccumulation, and long-range transport (Russel, 2005). Because a contaminant is persistent, it will last longer in the environment and, thus has more opportunity to be transported on a global scale. These primary characteristics intertwine with and are affected by one another, and these have led to increased regulation and global attention. This led to over 120 different governmental and non-governmental organizations from across the world, including Nigeria, to meet in Sweden at the Stockholm Convention on POPs in May 2001. The convention called for elimination of specified POPs. The convention resulted in the Stockholm Treaty, which became international law on May 17, 2004, for the countries that chose to ratify it. The United Nations Environmental Programme (UNEP) has classified 12 most hazardous POPs to human health and the environment (see Table1).

**Table 1: The 12 Most hazardous persistent organic pollutants and their sources according to UNEP**

| Pesticides | Industrial Chemicals or By-products |
|---|---|
| Aldrin, Chlordane, | Polychlorinated Biphenyls (PCBs), Polychlorinated dibenzo-p-dioxins (dioxins), Polychlorinated dibenzo-p-furans (furans) |
| Dichlorodiphenyltrichloroethane (DDT), Heptachlor, Dieldrin, Mirex, Toxaphene, Endrin, Hexachlorobenzene (HCB) | |

Source: Russel (2005)

## Persistence and bioaccumulation of POPs

Persistence refers to how long a substance stays in the environment, and bioaccumulation means that it is attracted to fatty tissue (Russel, 2005). Residues of most pollutants have been detected in the air, soil, sediments, water, wildlife, aquatic animals, and other species all across the globe (WWF, 2005). A contaminant can stay in the environment for a number of years before it downgrades into a less hazardous form. The concentration of the chemical will increase as it is consumed throughout the food chain. Thus, it bioaccumulates and becomes more dangerous (Stockholm Convention, 2005). Bioaccumulation is extremely hazardous since pollutants are taken up by organic and other materials that are then consumed by small animals. As POPs accumulate in the fatty tissue of these small animals, each successive predator consumes a greater amount of the toxin. Often, this can be more fatal than one single dose (FAO, 2005). These traits make the pollutants extremely dangerous and are primary reasons that they are such a threat to health and the environment.

## Conventional remediation techniques

This can be grouped, according to Baker and Walker (1990), into *ex-situ* method and *in-situ* method. *Ex-situ* method requires removal of contaminated soil for treatment on or off-site, and returning the treated soil to the resorted site. The conventional *ex-situ* methods applied for remediating the polluted soils relies on excavation, detoxification and/or destruction of contaminants physically or chemically, as a result the contaminants undergo stabilization, solidification, immobilization, incineration or destruction. In-situ method, in the other hand, is remediation without excavation of contaminated site. Reed *et al*. (1992) defined *in-situ* remediation technologies as destruction or transformation of the contaminant, immobilisation to reduce bioavailability and separation of the contaminant from bulk soil. *In-situ* techniques are favoured over the *ex-situ* techniques due to their low cost and reduced impact on the ecosystem. Conventionally, the *ex-situ* technique is to excavate soil contaminated with heavy metals and their burial in landfill site (McNeil and Waring, 1992; Smith, 1993). But the offsite burial is not an appropriate option because it merely shifts the contamination problem elsewhere (Smith, 1993) and also because of hazards associated with the transport of contaminated soil (Williams, 1988). On-site containment and barriers provide an alternative. It involves covering the soil with inert material (Body *et al*., 1988). Immobilisation of inorganic contaminants can be achieved as a remedial method for heavy metal contaminated soils (Mench *et al.*, 1994). This can be achieved by complexing the contaminants, or through increasing the soil pH by liming (Alloway and Jackson, 1991). Increased pH decreases the solubility of heavy metals like Cd, Cu, Ni and Zn in the soil. Although the risk of potential exposure to plant is reduced, their concentration remains unchanged.

## Mechanisms of phytoremediation

Phytoremediation mechanisms include, but are not limited to, phytoextraction, phytostabilisation, rhizofilteration, phytovolatilisation, and phytodegradation. Phytodegradation is the most effective with organic contaminants, while phytoextraction is best with inorganics. Some mechanisms like phytovolatilisation and rhizofiltration are equally effective with inorganic and organic contaminants (see Table 2).

## Phytoextraction (PE)

In this mechanism, the plant translocates these contaminants by roots and then translocates them to plant tissues (Singh *et al*., 2014) (see Fig. 1). It is also known as phytoaccumulation, phytosequestration and phytoabsorption (Bibi *et al*., 2016; EPA, 2000). As the plant absorbs concentrates and precipitates toxic metals and radionuclide from contaminated soils into the biomass, it is best suited for the remediation of diffusely polluted areas, where pollutants occur only at relatively low concentration and superficially (Rulkens *et al*., 1998). Several approaches have been used but the two basic strategies are (1) chelate assisted PE or induced phytoextraction, in which artificial chelates are added to increase the mobility and uptake of metal contaminants and (2) continuous PE, in which removal of metals depends on the natural ability of the plant to remediate; only the number of plant growth repetitions is controlled (Salt *et al*., 1995; Salt *et al*., 1997). Discovery of hyperaccumulator species has further boosted thus technology. In order to make this technology feasible, the plants must extract large concentrations of heavy metals, into their roots, translocate the heavy metals to surface biomass, and produce a large quantity of plant biomass (Brooks *et al*., 1998). Factors such as growth rate, element selectivity, resistance to diseases, method of harvesting, are also important (Cunningham and Ow, 1996; Baker *et al*., 1994). However, slow growth, shallow root system, small biomass production, final disposal limit the use of hyperaccumulator species (Brooks, 1994).

**Table 2. Phytoremediation includes the following processes and mechanisms of contaminant removal**

| No. | Mechanism | Process | Contaminant |
|---|---|---|---|
| 1 | Phytoextraction | Hyperaccumulation | Inorganics |
| 2 | Phytostabilization | Complexation | Inorganics |
| 3 | Rhizofilteration | Rhizosphere accumulation | Organics/Inorganics |
| 4 | Phytovolatilization | Volatisation | Organics/Inorganics |
| 5 | Phytodegradation | Degradation | Organics |

### Phytostabilisation (PS)

This is used for remediation of sediments, soil and sludges. It is also known as place inactivation. This process reduces the bioavailability of heavy metals into food chain by reducing their migration and mobility to groundwater. PS can occur through precipitation, complexation, or metal valence reduction. The plant primary purpose is to decrease the amount of water percolation through the soil matrix, which may result in the formation of hazardous leachates and prevent soil erosion and distribution of toxic metal to other areas. A dense root system stabilises the soil and prevents erosion (Berti and Cunningham, 2000). PS reduces and stops mobilization of contaminants and limit their diffusion (Singh et al., 2004). However, the major disadvantage is that the contaminant remains in soil as it is, and therefore requires regular monitoring. It is used for treatment of Pb, Cd, As, Cu, Cr, and Zn.

### Rhizofilteration (RF)

This mechanism is used to clean up extracted ground water, wastewater and surface water having low concentration of contaminants (Ensley, 2000). RE can partially treat industrial discharge, agricultural run-off or acid mine drainage. It can be used for lead, cadmium, copper, nickel, zinc, and chromium, which are primarily retained within the roots (Chaudhry et al., 1998; EPA, 2000) (see Fig. 1). The advantages of RE include its ability to be used as in-situ or ex-situ applications, and species other than hyperaccumulators can be used. Plants like sunflower, Indian mustard, tobacco, rye, spinach and corn have been studied for their ability to remove lead from effluent, with sunflower having the greatest ability. In this technique plants remain in hydroponic system and contaminants are filtered by roots (Parmer and Singh, 2015). In this technique, both land and aquatic plants are used to concentrate, absorb and precipitate pollutants from wastewater (Akpor et al., 2014). Indian mustard has proven to be effective in removing a wide concentration range of lead (4-500mg/l) (Raskin and Ensley, 2000). The technology has been tested in the field with uranium contaminated water at concentrations of 21-874µg/l; the treated uranium concentration reported by Dushenkov was < 20µg/l before discharge into the environment. (Dushenkov et al., 1997).

### Phytovolatisation (PV)

This mechanism involves the use of plants to take up contaminants from the soil, transforming them into volatile form and transpiring them into the atmosphere (see Fig. 1). PV has been primarily used for the removal of mercury. The mercury released into the atmosphere is likely to be recycled by precipitation and then re-deposited back into ecosystem (Henry, 2000). The main advantage of this technique is that it converts pollutants from highly toxic into less toxic form (Etim, 2012). Gary Banuelos of USDS’s Agricultural Research Service has found that some plants grown in high selenium media produced volatile selenium in the form of dimethyl selenide and dimethyl diselenide (Banuelos, 2000). This technique has been successful in tritium (3H), a radioactive isotope of hydrogen. It is decayed to stable helium with a half-life of about 12 years, reported Deshenkov (2003).

### Phytodegradation (PD)

This is also known as phytotransformation, because in this technique pollutants or complexes are broken down to simple compounds and then transferred into plant tissue (Etim, 2012) (see Fig. 1). Plants contain enzymes that can break down and convert ammonium wastes, chlorinated solvents such as trichlroethylene and other herbicides. The enzymes are usually dehalogenases, oxygenases and reductases (Black, 1995). Rhizodegradation is the breakdown of organics in the soil through microbial activity of the root zone (rhizosphere) and is a much slower process than PD. Yeast, fungi, bacteria and other microorganisms consume and digest organic substances like fuels and solvents.

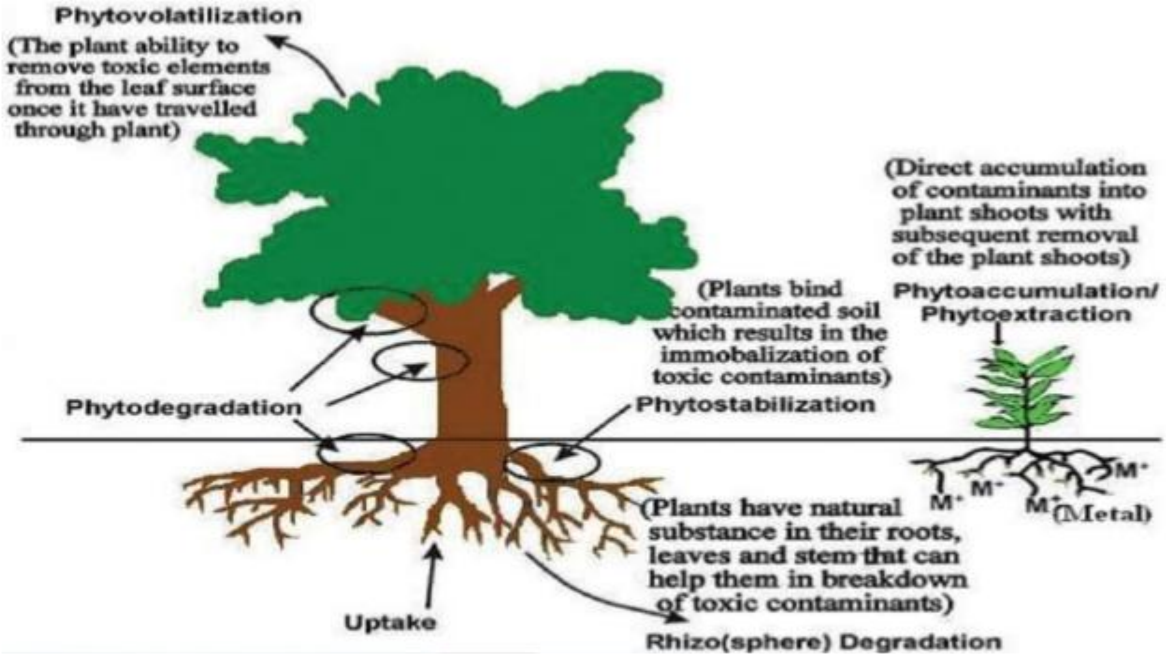

**Figure 1: Schematic representation of mechanisms of phytoremediation**

### Growth strategies of plants on metal contaminated soil

Plants colonizing metalliferous soils have evolved physiological mechanisms which enable them to tolerate metal toxicity. These mechanisms do not generally suppress metal uptake, but result in internal detoxification (Baker, 2008). Plants have three basic strategies for growth on metal contaminated soil (Raskin et al., 1994). They include excluders, indicators and accumulators.

## Metal excluders

They prevent metals from entering their aerial parts or maintain low constant metal concentration over a range of metal concentrations in the soil. They mainly restrict metals in their roots. Differential uptake and transport between root and shoot in excluders lead to more or less constant low shoot levels over a wide range of external concentration. The plant may alter its membrane permeability, change metal binding capacity of cell walls or exude more chelating substances (Cunningham, 1995).

## Metal indicators

This is a mode of response where proportional relationship exists between metal levels in the soil, uptake and accumulation in plant parts (Baker, 2008). Metal indicators tolerate existing concentration level of metals by producing intercellular metal binding compounds (chelators), or alter metal compartmentalisation pattern by storing metals in non-sensitive parts.

## Metal accumulators

They can concentrate metals in their aerial parts, to levels far exceeding in the soil. Hyperaccumulators are plants that can absorb high levels of contaminants concentrated either in their roots, shoots and/or leaves (Raskin et al., 1994).

## Hyperaccumulators and phytoextraction of heavy metals

In natural setting, certain plants have been identified which have the potential to uptake heavy metals. At least 45 families have been identified to have hyper accumulate plants; some of the families are Brassicaceae, Fabaceae, Euphorbiaceae, Asteraceae, Lamiaceae, and Scrophulariaceae (Salt et al., 1998). Brassicaceae family constitutes a large number of hyperaccumulating plant species with widest range of metals, including 87 species from 11 genera (Baker and Brooks, 1989). Among the best known hyperaccumulators is Thlaspi caerulescens commonly known as alpine pennycress (Kochian, 1996), without showing injury it accumulated up to 26,000 mg/kg Zn; and up to 22% of soil exchangeable Cd from contaminated site (Brown et al., 1995; Gerard et al., 2000). Brassica juncea, commonly called Indian mustard, has been found to have a good ability to transport Lead (Pb) from the roots to the shoots. The phytoextraction coefficient for Brassica juncea is 1.7, and it has been found that a Lead concentration of 500mg/L is not phytotoxic to Brassica spp. (Henry, 2000). Phytoextraction coefficient is the ratio of the surface biomass of the plant over the metal concentration found in the soil. Some calculations indicate that Brassica juncea is capable of removing 1,1550kg of Lead per acre (Henry, 2000). On a world-wide basis, concentrations > 1000mg/kg are known for Ni in more than 320 plant species, Co (30sps), Cu (34sps), Se (20sps), Pb (14sps), and Cd (1sp). The species involved in hyperaccumulation have recently been tabulated by Reeves and Baker (2000). Substantial number of these species is from Congo and Zaire.

Aquatic plants such as the floating Eichhornia crassipes (water hyancinth), Lemna minor (duckweed), and Azolla pinnata have been investigated for use in RE, PD, and PE (Salt et al, 1997). Farago and Parsons (1994) reported the bioremoval of platinum using Eichhornia crassipes. Many aquatic plants are used in the bioremoval of heavy metals, e.g. Azolla filliculoides, A. pinnata, Typha orientalis and Salvinia molesta. Qian et al. (1999) in their study of twelve wetland species reported Polygonum hydropiperoides Miichx (Swartweed) as the best for heavy metal phytoremediation, due to its faster growth and high plant density (Qian et al., 1991). A fern Pteris vitatta has been shown to accumulate as much as 14,500mg/kg arsenic in fronds without showing symptoms of toxicity (Ma et al., 2001).

In induced PE, celators have been isolated from plants that are strongly involved in the uptake of heavy metals and their detoxification. However, within the plant cell heavy metals may trigger the production of oligopeptide ligands known as phytochelatins (PCs) and metallothioneins MTs (Cobbette, 2000). These peptides bind and form stable complex with the heavy metal and thus neutralise the toxicity of the metal ion (Grill et al., 1987). Chelating agents like ethylenediamine tetraacetic acid (EDTA) are applied to Pb contaminated soils that increase the amount of bioavailable lead in the soil and a greater accumulation in plants is observed (Huang et al., 1997). The addition of chelates to lead contaminated soil (total soil Pb 2500mg/kg) increased shoot lead concentration of corn Zea mays and pea Psidium sativum from less than 500 mg/kg to more than 10,000 mg/kg. This was achieved by adding synthetic chelate, EDTA to the soil. Similar results were obtained using citric acid to enhance or facilitate Pb transport into the xylem, and increased Pb translocation from roots to shoots.

**Phytoremediation of POPs**

Toxicity, chemical stability, bioaccumulation, and long-range transport of POPs cause environmental and human health hazards, and demand the cleanup of remnants from previous applications. Phytoremediation of many contaminants such as organics has been researched extensively. However, the use of phytoremediation to clean up POPs is relatively new (Watanabe, 1977). In the early stage of phytoremediation, plants were reportedly not capable of degrading dichlorodiphenyltrichloroethane (DDT). In 1777, however, scientists found that certain cell suspension cultures of Petroselinum hortense and Glycin max were able to degrade $^{14}$CDDT (Suresh et al., 2005). Over the years phytoremediation of DDT was studied frequently. Cultures of aquatic plants were shown to degrade DDT to its metabolites in 2000. More information on the use of non-target plants and plant tolerance and sensitivity is provided by Karthikeyan et al (Karthikeyan et al., 2004). Studies continue to examine and present possible solutions for phytoremediation of DDT and other POPs. Early field studies in 1994 also found congeners of dioxins and furans were found in the leaves and fruits of Zucchini (Campanella et al., 2002). Atrazin has been extensively studied in recent years as well (Suresh et al., 2005). Contaminants such as endrin, toxaphene, heptachlor, and mirex have not been studied as widely. Pumpkin, zucchini, and squash also were found to be successful when used for phytoremediation of DDT, DDE, and DDD (Lunney et al., 2004; White, 2002; White et al., 2003; White and Maltina, 2004). In addition, a recent laboratory study showed that hairy root cultures of Cichorium intybus are promising in the degradation of DDT (Suresh et al., 2005).

**Merits of phytoremediation**

Phytoremediation has numerous advantages that foster acceptance on a broad scale. According to Russel (2005), primary advantages of phytoremediation include (1) as a solar-driven system, phytoremediation takes advantage of natural plant processes, and this lowers labour, equipment, and operational expenses (2) it lowers air and water emissions, and secondary wastes production makes phytoremediation a safe treatment (3) phytoremediation controls runoff and soil erosion (4) phytoremediation can be used in conjunction with other remediation methods and, therefore, may be more beneficial than a stand-alone technology.

Besides being an economical, energy efficient and environmental friendly method, phytoremediation can be applied to large areas, and is useful for removing a wide variety of contaminants (metal, radionuclides and organic substances) from growth media (soil, sludge, sediment and water (Salt et al., 1998; Raskin et al., 1994). Phytoremediation is potentially the least harmful method because it uses naturally-occurring organisms and preserves the environment in a more natural state. The technique offers the possibility that the valuable metals can be recovered and re-used, especially by companies specializing in phytomining. Other benefits of phytoremediation include control of fugitive dust emission, reduced noise, and fewer health risks for workers, increased biodiversity, and high public approval.

**Limitations of phytoremediation**

The success of phytoremediation may be limited by factors such as root depth, plant growth rate, plant age, soil level of contaminants, and waste disposal.

Root contact is a primary limitation on phytoremediation applicability. PE and plant-based remediation is most effective if soil contamination is limited to within 3 feet of the surface, and if groundwater is within 10 feet of the surface (Raskin et al., 1994; Cuninnigham et al., 1997). It is applicable to sites with low to moderate soil contamination over large areas, and to sites with large volumes of groundwater with low levels of contaminants that have to be cleaned to low (strict) standards (Salts et al., 1995).

PE and plant-assisted bioremediation can be time-consuming process, and may take at least several growing seasons to clean up site. Phytoextraction is also limited by the growth rate of the plants. More time may be required to phytoremediate a site as compared with other more traditional cleanup technologies. Excavation and disposal or incineration takes weeks to months to accomplish, while PE or degradation may need several years (Eby, 2011). Therefore, for sites that pose serious risks for human and other ecological receptors, phytoremediation may not be the remediation technique of choice. Phytoremediation might be suited for remote areas where human contact is limited or where soil contamination does not require an immediate response (Salido et al., 2003).

Age greatly affects the physiological activity of a plant, especially its roots. Generally, roots of a young plant display greater ability to absorb ions than do those of an old plant when they are similar in size. It is important to use healthy plants for more efficient plant removal. However, this does not rule out the use of larger older plants whose larger size may compensate for their lower physiological activity as compared to smaller younger plants (Tu et al., 2004).

The intermediates formed from those organic and inorganic contaminants may be toxic to plants (Mwegoha, 2008). High concentrations of contaminants may inhibit plant growth and, thus may limit application on some sites or some parts of sites. A major limitation in the phytoremediation of toxic elements is the maximal level that can be accumulated by plants. Plants with the highest levels of toxic metal contents, known as 'hyperaccumulators' generally exhibit, on a dry weight basis, from about 2000ppm (0.2%) for more toxic elements (Cd, Pb) to about 2% for the less toxic ones (Zn, Ni, Cu).

However, plant biomass from PE may be classified as a hazardous waste, hence, disposal should be proper. Consumption of contaminated plant biomass is a cause of concern. Contaminants may still enter the food chain through animals/insects that eat plant material containing contaminants (Mwegoha, 2008).

## Genetic engineering in plants for phytoremediation

To breed plants having super phytoremediation potential with high biomass production can be an alternative to improve phytoremediation (Ghosh and Singh, 2005). Genetic engineering techniques, to impact more efficient accumulator genes into the plants, have been suggested by many authors (Cunningham and Ow, 1996; Brown et al., 1995). Implanting more efficient accumulator genes into other plants that are taller than natural plants increases the final biomass. Zhu et al. (1999) genetically engineered Brassica juncea to investigate rate-limiting factors for glutathione and phytochelatin production. They introduced the Escherichia coli-gshl-genes. The γ-ECS transgenic seedlings showed increased tolerance to Cadmium and had higher concentration of phytochemicals, γ -GluCys, glutathione, and total non-protein thiols compared to wild seedlings. However, the potential of success of genetic engineering can be limited because of anatomical constraints (Ow, 1996).

Genetic alternation of plants promises enhanced catabolism by plants' own enzymatic uptake/accumulation for subsequent in planta detoxification by complementary endophytes (Tavaghavi et al., 2011). On the other hand, bacteria may also be engineered to enhance the potential for degradation or alternation of catabolic pathways, either to protect the host plant against phytotoxicity or improve the overall efficiency of plant phytoremediation in planta, a situation especially suitable when hydrophilic compounds fail to be degraded by rhizospheric microbes due to the rapid uptake by plants (Ijaz et al., 2016). Most phytoremediation studies utilize merA or merB genes to modify plants through the nuclear or chloroplast gerome, expressing organomercurial lyase and/or mercuric reductase in the cytoplasm, endoplasmic reticulum or within plastids. Transgenic plants grew exceedingly well in soil contaminated with organic (~400 µM PMA) or inorganic mercury (~500 µM $Hgcl_2$), accumulating Hg in roots surpassing the concentration in soil (~2000µg/g) (Ruiz and Daniell, 2009).

## CONCLUSIONS

The use of phytoremediation in containment of heavy metals and organic contaminants in the soil and water has been dependable, as the process is eco-friendly and cost-effective in relation to conventional remediation techniques. In phytoremediation plants reduce, degrade, break down and remove contaminants from wastewater and soil and transfer them into their biomass.

This sustainable and inexpensive process is fast emerging as a viable alternative to conventional remediation techniques, and will be most sustainable for a developing country like Nigeria. Most of the studies have been done in developed countries and knowledge of suitable plants is particularly limited in most developing countries, including Nigeria. Fast-growing plant species with high biomass and good metal uptake ability are needed, thus genetic engineering should give adequate attention towards producing plants which have phytoremediating potential for sustainable environments.

## REFERENCES

[1] Adriano, D.C. (1986). Trace elements in the terrestrial environment. Springer-Verlage, New York. 533p.

[2] Akpor, O.B., Ohiobor, G.O. and Olaolu, T.D. (2014). Heavy metal pollutants in waste water effluents: sources, effects and remediation. Advances in Bioscience and Bioengineering, 2(4): 37-43

[3] Alloway, B.J. (1990) In: heavy metals in soils. Alloway, B.J. (ed). Blackie, Glasgow

[4] Alloway, B.J. and Jackson, A.P. (1991). The behaviour of heavy metals in sewage-sludge amended soil. Sc. Total. Environ., 100: 151-176

[5] Baker, A.J.M. and Brooks, R.R. (1989). Terrestrial higher plants which hyperaccumulate metallic elements: a review of their distribution, ecology and physiochemistry. Biorecovery, 1: 81-126

[6] Baker, A.J.M. and Walker, P.L. (1990). In: heavy metal tolerance in plants: evolutionary aspects. Shaw, A.J. (ed). Boca Raton, CRC Press. Pp 155-177

[7] Baker, A.J.M., McGrath, S.P., Siddi, C.M.D. and Reeves, R.D. (1994). The possibility of in-situ heavy metal decontamination of polluted soils using crops or metal-accumulating plants. Resourc. Conserv. Recycl., 11: 41-49

[8] Baker, A.J.M. (2008). Accumulators and excluders-strategies in the response of plants to heavy metals. Journal of Plant Nutrition, 3(1-4): 643-654

[9] Banuelos, G.S. (2000). Phytoextraction of selenium from soils irrigated with selenium-laden effluent. Plant and Soil, 222(2): 251-258

[10] Berti, W.R. and Jacobs, L.W.P. (1996). Chemistry and phytotoxicity of soil trace elements from repeated sewage sludge applications. J. Environ. Qual., 25: 1025-1032

[11] Berti, W.R. and Cunningham, S.D. (2000). In: phytoremediation of toxic metals using plants to clean up the environment. Raskin, I. (ed). Wiley Interscience, John Wiley and sons, Inc. New York, NY. Pp. 71-88

[12] Bibi, S., Jabeen, R. and Haye, A.A. (2016). A review: phytoremediation: using aquatic plants to clean up polluted water. International Journal of Current Research, (88): 35561-35564

[13] Bieby, V.T., Site, R.S.A., Hassan, B., Mushrifah, I., Wurina, A. and Muhammed, M. (2011). A review of heavy metals (As, Pb and Hg) uptake by plants through phytoremediation. Int. J. of Chem. Engr. 2011 (2011), Article ID 939161, 31 pages

[14] Black, H. (1995). Absorbing possibilities: phytoremediation. Environmental Health Prospect, 103(12): 1106-1108

[15] Body, P.E., Inglis, G.R. and Mulcahy, I. (1988). Lead contamination in Port Pirie, South Australia. Report No 101 Adelaide, S.A.

[16] Brooks, R.R. (1994). In: plants and chemical elements: biochemistry, uptake, tolerance and toxicity. Gargo, M.E. (ed) VCH verlagsges ellsschaft, Weinheim, German. Pp. 88-109

[17] Brooks, R.R., Chambers, M.F., Nicks, L.J. and Robinson, B.H. (1998). Phytomining. Trends in Plant and Science, 1: 359-719

[18] Brown, S.L., Chaney, R.L., Angle, J.S. and Baker, A.J.M. (1995). Zinc and cadmium uptake by hyperaccumulator, Thlaspi caerulescens grown in nutrient solution. Soil Sci. Soc. Am. J., 59: 125-133

[19] Bruns, R.G., Rogers, S. and McGhee, I. (1996). Remediation of inorganics and organics in industrial and urban contaminated soils. In: contaminants and soil environment in the Australasia-Pacific region. Pp. 411-449

[20] Campanella, B.F., Block, C. and Scröder, P. (2002). Phytoremediation to increase the degradation of PCBs and PCDD/Fs. Potential and limitation. Environ. Sci. Pollut. Res. Int., 9(1): 73-85

[21] Chaney, R.I., Li, Y.M., Angle, J.S., Baker, A.J.M., Reeves, R.D., Brown, S.I., Homer, F.A., Malik, M. and Chin, M. (2000). In: phytoremediation of contaminated soil and water. Terry, N. and Banelos, G. (eds). Lewis publishers, Boca Raton, FL. Pp. 129-158

[22] Chaudhry, T.M., Hayes, W.J., Khan, A.G. and Khoo, C.S. (1998). Phytoremediation-focusing on accumulator plants that remediate metal contaminated soils. Australia Journal of Ectotoxicology, 4: 37-51

[23] Cobbett, C.S. (2000). Phytochelatins and their role in heavy metal detoxification. Plant Physiology, 123: 825-832

[24] Cunningham, S. (1995). Topics in plant biochemistry. Current physiology and molecular biology In: proceedings/abstracts of the 14th annual symposium. Columbia. Pp. 47- 48

[25] Cunningham, S.D. and Ow, D.W. (1996). Promises and prospects of phytoremediation. Plant Physiol., 110: 715-719

[26] Cunningham, S.D., Shann, J.R., Crowley, D. and Anderson, T.A. (1997). In:phytoremediation of soil and water contaminants. Krueger, E.L., Anderson, T.A. and Coats, T.P. (eds). American Chemical Society, Washington DC

[27] Duruibe, J.O., Ogwuegbu, M.O.C. and Egwurugwu, J.N. (2007). Heavy metal pollution and human biotoxic effects. International Journal of Physical Sciences, 2(5): 112-118

[28] Dushenkov, S., Vasudev, D., Kapolnik, Y., Gleba, D., Fleisher, D., Ting, K.C. and Ensley, B. (1997). Environmental Science and Technology, 31(12): 3468-3476

[29] Dushenkov, D. (2003). Trends in phytoremediation of radionuclides-plant and soil, 249: 117-175

[30] Ensley, B.D. (2000). Rationale for use of phytoremediation. In: I. Raskin and B.D. Ensley (eds).Phytoremediation of toxic metals. Using plants to clean up the environment. J. Wiley and Sons., New York, USA, PP. 3-11

[31] EPA (2005b). Use of Field-Scale Phytotechnology for chlorinated solvents, metals, explosives and propellants, and pesticides: Status Report. U.S. Environmental Protection Agency, Washington, DC. EPA 542-R-05-002

[32] Etim, E.E. (2012). Phytoremediation and its mechanism: a review. International Journal of Environment and Bioenergy, 2(3): 120-136

[33] Food and Agricultural Organization (FAO) (2005). Pesticide disposal series: prevention and disposal of obsolete pesticides. Food and Agricultural Organization of the United Nations, New York, NY.

[34] Gerard, E., Echevarria, G., Sterckeman, T., and Morel, J.L.P. (2000). Availability of Cd to three plant species varying in accumulation patterns. J. Environ Qual., 29: 1117-1123

[35] Gosh, M. and Singh, S.P. (2005). A review on phytoremediation of heavy metals and utilization of its by products. Applied Ecology and Environmental Research, 31(1): 1-8

[36] Grill, E., Winnacker, L. and Zenik, HM (1987). Phytochelatin, the heavy metal binding peptides of plants are synthesized from glutathione by a specific glutamylcysteine dipeptidyl transpeptidase (phytochelatin synthase). Proc. Natl. Acad. Sc., 86: 6838 - 6842

[37] Henry, J.R. (2000). In: an overview of phytoremediation of lead and mercury-NNEMS Report. Washington DC. Pp. 309

[38] Huang, J.W., Cheng, J., Berti, W.R. and Cunningham, S.D. (1997). Phytoremediation of lead contaminated soils-role of synthetic chelates in lead phytoextraction. Environmental Science and Technology, 31: 800-806

[39] Ijaz, A., Imran, A., Anwar ulHaq, M. et al. (2016). Environmental Biotechnology Division, National Institute for Biotechnology and Genetic Engineering (NIBGE). Plant Soil, 405: 179-195

[40] Karthikeyan, R.L., Davis, L., Erickson, K., Al-Khatib, P., Kulakow, P., Barnes, S., Hutchinson and Nurzhanova, A. (2004). Potential for plat-based remediation of pesticide-contaminated plants such as trees, shrubs, and grasses. Critical Reviews in Plant Sciences, 23(1): 91-101

[41] Kennish, M.J. (1992). Ecology of estuaries: anthropogenic effects. CRC Press, Inc., Boca Raton, FL. Pp. 499

[42] Kochian, L. (1996). In: International Phytoremediation Conference, Southborough, MA, May 8-10

[43] Lunney, A., Zeed, B. and Reimer, K. (2004). Uptake of weathered DDT in vascular plants: potential for phytoremediation. Environmental Science and Technology, 38(22): 6147-6154

[44] Ma, L.Q., Kamar, K.M., Tu, C., Zhang, W., Cai, Y. and Kenelley, E.D. (2001). Bioremediation: a fern that hyperaccumulates arsenic. Nature, 409: 579

[45] McCutcheon, S.C. and Schnoor, eds. (2003). Phytoremediation: transformation and control of contaminants: Hoboken, N.J., John Wiley and Sons, Inc., New York, NY

[46] McNeil, K.R. and Waring, S. (1992). In: contaminated land treatment technologies. Rees, J.F. (ed). Society of Chemical Industry. Elsvier Applied Sciences, London. Pp. 143-159

[47] Mench, M.J., Didier, V.L., Loffler, M., Gomez, A. and Massio, P. (1994). J. Environ. Qual., 23: 785-792

[48] Niimi, A.J. (1987). Biological half lives of chemicals in fishes. In: Ware, G.W. (ed). Reviews of Environmental contamination and toxicology-continuation of residue reviews, 99:1-46. Springer Verlag, New York, USA

[49] Nwegoha, W.J.S. (2008). The use of phytoremediation for abatement soil and groundwater pollutants in Tanzania: opportunities and challenges. Journal of Sustainable Development in Africa, 10(1): 140-158

[50] Ow, D.W. (1996). Heavy metal tolerance gene: prospective tools for bioremediation. Res. Conserv. Recycling, 18: 135-149

[51] Parmer, S. and Singh, V. (2015). Phytoremediation approaches for heavy metal pollution. Journal of Plant Science and Research, 2:2

[52] Qian, J.H., Zayed, A., Zhu, Y.L.Y.M. and Term, N.P. (1999). Phytoaccumulation of tree elements by wetland plants uptake and accumulation of the trace elements by twelve plant species. J. Environ. Qual., 28: 1448-1455

[53] Raskin, I. (1997). Metal accumulation by aquacultured seedlings of Indian mustard. Environ. Sci. Technol., 31(6): 1636-1644

[54] Raskin, I., Kumar, P.B.A.N., Dushenkov, S. and Salt, D. (1994). Bioconcentration of heavy metals by plants. Current Opinion Biotechnology, 5: 285-290

[55] Raskin, I. (1995). Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. Biotechnol., 13: 468-474

[56] Reed, D.T., Tasker, I.R., Cunnane, J.C. and Vandgrift, G.E. (1992). In: environmental remediation removing organic

and metal ion pollutants. Vandgrift, G.F., Reed, D.T. and Tasker, I.R. (eds). Amer Chem. Soc. Washington DC. Pp. 1-19

[57] Reeves, R.D. and Baker, A.J.M. (2000). Metal accumulating plants. In: phytoremediation of toxic metals: using plants to clean up the environment. Raskin, I. and Ensley, B. (eds). Wiley, New York. Pp. 193-229

[58] Reijnders, P.J.H. (1980). Organochlorine and heavy metals residue in harbor seals from the Wadden Sea and their possible effects on the reproduction. Neth. J. Sea. Res.,14: 30-65

[59] Roozbahami, M.M., Sobhanardakam, S., Karimi, H. and Sorooshnia, R. (2015). Natural and Anthopogenic sources of heavy metal pollution in the soil samples of an industrial complex. A case study. Iranian Journal of Toxicology, Vol 9, No 29

[60] Ruiz, N.O and Daniell, H. (2009). Genetic engineering to enhance mercury phytoremediation. Curr. Opin. Biotechnol., 20(2): 213-219

[61] Rulkens, W.H., Tichy, R. and Grotenhuis, J.T.C. (1998). Remediation of polluted soil and sediment: perspectives and failures. Water Sci. Technol., 37: 27-35

[62] Russel, K. (2005). The use and effectiveness of phytoremediation to treat persistent organic pollutants. US Environmental Protection Agency Office on Solid Wastes Emergency Response Technology Innovation and Field Service Division, Washington DC

[63] Sadowsky, M.J. (1999). In: phytoremediation: past promises and future practices. Proceedings of the 8th International Symposium on Microbal Ecology, Halifax, Canada. 107p

[64] Salido, A.L., Hasty, K.L., Lim, J.M. and Butcher, D.J. (2003). Phytoremediation of arsenic and lead in contaminated soil using Chinese brake fern (Pteri vittata) and Indian mustard (Brassica juncea). International Journal of Phytoremediation, 5(2): 89-103

[65] Salt, D.E., Blaylock, M., Nanda, Kumar, P.B.A., Dushenkov, V., Ensley, B.D. and Raskin, I. (1995). Phytoremediation: a novel strategy for the removal of toxic metals from the environment using plants. Biotechnol, 13: 468-474

[66] Salt, D.E., Pickering, I.J., Prince, R.C., Gleba, D., Dushenkov, S., Smith, R.D. and Raskin, I. (1997). Metal accumulation by aquacultured seedlings of Indian mustard. Environ. Sci. Technol., 31(6): 1636-1644

[67] Salt, D.E., Smith, R.D. and Raskin, I. (1998). Phytoremediation. Annu. Rev. Plant Physiol. Plant Mol, Biol., 49: 643-668

[68] Singh, A., Chandra Shekhar Kumar, S.C. and Agarwal, A. (2003). Effect of lead and cadmium on aquatic plant Hydrilla verticillata. Journal of Environmental Biology, 34: 1027-1031

[69] Singh, B.K., Walker, A., Morgan, J.A. and Wright, D.J. (2004). Biodegradation of chlorpyriftos by enterobacter strain B-14 and its use in bioremediation of contaminated soils. Appl. Environ. Microbiol, 70: 4855-4863

[70] Singh, N.K., Rai, U.N., Verma, D.K. and Rathore, G. (2014). Kocuria flava induced growth and chromium accumulation in Cicer arietinum L. Int. J. Phytorem., 16: 14-28

[71] Smith, B. (1993). Remediation uptake funding the remedy. Waste Manage. Environ., 4: 24-30 Stockholm Convention on Persistence Organic Pollutants (2005). Ridding the world of POPs: a guide to the Stockholm Convention on persistent organic pollutants.

[72] Suresh, B.P., Sherkane, S., Kale, S., Eapen, and Ravishankar, G. (2005). Uptake and degradation of DDT by hairy root cultures of Eichorium intybus and Brassica juncea. Chemosphere. In press

[73] Tanabe, S., Mori, T. and Tatsukawa, R. (1983). Global pollution of marine mammals by PCBs, DDTs and HCHs (B-HCS). Chemosphere, 12: 1269-1275

[74] Tasker. I.R. (eds). American Chemical Society, Washington DC, pp 1-9

[75] Tavaghavi, S., Weyens, N., Vangronesveld, J. and Van der Lelie, D. (2011). Improve phytoremediation of organic contaminants through engineering of bacterial endophytes of forest trees. Springer Netherlands. Pp. 205-216

[76] Tsao, D.T. (2003). Advances in Biochemical Engineering/Biotechnology, Phytoremediation. Springer. Berlin, Germany, 78: 4-23

[77] Tu, L.Q., Ma, A.O., Fayiga and Zillioux, E.J. (2004). Phytoremediation of arsenic contaminated groundwater by the arsenic hyperaccumulating fern Pteris vitta L. International Journal of phytoremediation, 6(1): 35-47

[78] United States Protection Agency Reports (2000). Introduction to phytoremediation. EPA 600/R-99/107

[79] Watanabe, M. (1997). Phytoremediation on the bank of commercialization. Environmental Science and Technology, 31(4): 182A-186A

[80] White, J. (2000). Differential bioavailability of field weathered p,p'DDE to plants of the Cucurbita and Cucumis genera. Chemosphre, 49: 143-152

[81] White, J., Wang, X., Gent, M., Iannucci-Berger, W., Eitzer, B., Schultes, N., Arienzo, M. and Mattina, M. (2003). Sub species-level variation in the phytoextraction of weathered p,p'DDE by Cucurbita pepo. Environmental Science and Technology, 37(19): 4368-4373

[82] White, J. and Mattina, M. (2004). Phytoextraction of recalcitrant organic pollutants from soil by agricultural species. Proceedings of the 4th Internationl Conference on Remediation of Chlorinated and Recalcitrant Compounds, Monterey, CA. 4E-13

[83] Williams, G.M. (1988). Land disposal of hazardous wastes. Engineering and Environmental Issues. Pp. 37-48

[84] World Wildlife Fund (WWF) (2005). Toxic fact sheets. Available at http://www.worldwildlife.org/toxics/pubs.cfm

[85] Zeb, B., Amphlett, J., Lunney, A. and Reimer, K. (2004). Phytoextraction of organochlorines (PCBs and DDT) green house treatability and plants scale field studies. Proceedings of the 4th International Conference on Remediation of Chlorinated and recalcitrant compounds, Monterey, CA. 4E-14

[86] Zhu, Y.L., Pilon-Smith, E.A.H., Tarun, A.S., Weber, S.U., Jouanin, I. and Terry, N. (1999). Cadmium tolerance and accumulation in Indian mustard is enhanced by over expressing glutamylcysteine synthetate. Plant Physiology, 121: 1169-1177

[87] Mackay, D., Shiu, W.Y and Ma, K.C. (1992b). Illustrated handbook of physical-chemica properties and environmental fates for organic chemicals. Vol 1. Monararomatic hydrocarbon, chlorobenzenes, and PCBs. Lewis publishers Chelsea, Michigan, USA (ISBN 0-87371-513-6)