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Review Article

Phytoremediation technology, plant response to environmental contaminants and the need for soil augmentation

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Abstract

Contaminants in the environment occur naturally and/or through anthropogenic activities. These contaminants become a threat to all living organisms because of their increased in the environment and non-biodegradable nature. In order to protect the environment from these contamination, various techniques have been developed, and among them is phytoremediation. Phytoremediation is a technology that employed plant species for reclaiming contaminated soil, air, and water. This technology has been widely accepted in recent times, because of its low cost and environmentally friendly. In addition, augmentation of the contaminated soil, either chemo augmentation or bioaugmentation, have been used for the effective absorption of some of these contaminants. When the plants are grown in the contaminated sites, the contaminant in the soil maybe removed, immobilized, degraded or volatized. These phytoremediation technologies are: phytoextraction, phytovolatilization, rhizofiltration, phyto-stimulation, phyto-stabilization and phytodegradation. Based on the phytoremediation potentials of plants, pollutants are being removed from the environment thereby keeping the environment safe.

Keywords: bioavailability; contaminant; environment; metalloids; metals; phytoremediation

Introduction

Contaminants are available naturally or get to the environment via human activities. These contaminants can become deleterious and toxic when accumulated at higher concentration in the environment (Kabata-Pendias and Pendias, 2001; Oseni *et al.*, 2018). Metals or metalloids are elements whose densities are higher than 5 gcm^{-3}, and based on this definition, fifty-three elements fall into the category of metals or metalloids (Padmavathiamma and Loretta, 2007; Oseni *et al.*, 2016). Apart from metals (Pb, Zn, Cd, Cu, Ni,

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Hg) or metalloids (As, Sb), other pollutants are: inorganic compounds (NO_3^-, NH_4^+, PO_4^{3-}), radioactive chemical elements (U, Cs, Sr), petroleum hydrocarbons (BTEX), pesticides and herbicides (atrazine, bentazone, chlorinated and nitroaromatic compounds), explosives (TNT, DNT), chlorinated solvents (TCE, PCE), and industrial organic wastes (PCPs, PAHs) (Ensley, 2000). The buildup of these contaminants in the environment occurs naturally and or through anthropogenic activities such as volcanic eruption, wind erosion, forest fire, fossil fuel usage mining, electroplating, drilling, battery, cable manufacturing, automotive, textile, metal producing, sewage sludge pesticides, and fertilizer, etc. which pose health risk to living organisms (Tangahu *et al.*, 2011; Jaishankar *et al.*, 2014).

The most commonly occurring metals or metalloids in polluted site are: Cadmium (Cd), chromium (Cr), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni) and zinc (Zn). International Agency for Research on Cancer has classified them as metals and metalloids that are carcinogenic to human (Beyersman and Hartwig, 2008). The level of these metals in the environment has increased tremendously, and according to Singh *et al.* (2003); Usha *et al.* (2011), the annual worldwide release of cadmium is 22,000t (metric ton), 939,000t for copper, 783,000t for lead and 1,350,000t for zinc. Because of the annual increased of these heavy metals, there is a need to develop effective technologies for the management and remediation of the contaminated soil and water. Although there are conventional physicochemical remediation technologies such as soil washing, vapor extraction, incineration, solidification, thermal desorption, enzymatic degradation, adsorption and ion exchange which causes secondary air or groundwater pollution and reduce soil fertility (Muthusarayanan *et al.*, 2018).

Phytoremediation employed plants species for reclaiming polluted soil and water. In recent times, phytoremediation techniques have been widely employed because of its low cost and eco-friendly. By growing these plants in the contaminated sites, the contaminant in the soil will be removed, immobilized, degraded or volatilized. Also, the use of synthetic chelates, fertilizer, nitrogen fixing bacterial, and mycorrhizae, etc., for soil augmentation had been shown to dramatically enhance the bioavailability of these contaminants for plants uptake (Zhang, 2009). The plants selected for phytoremediation is based on their growth rate, biomass, the depth of their root zone, and their ability to tolerate and accumulate the contaminant (Oh *et al.*, 2013; Oseni *et al.*, 2018).

Since the buildup of these contaminants have become a threat to all living organisms and the environment, hence arises the phytoremediation technologies which are low cost and environmentally friendly. This review will look at the different phytoremediation technologies, the pollutants involves, the strategies, mechanism and augmentation of soils for effective phytoremediation.

Phytoremediation technologies

Phytoremediation technologies are the techniques that depend on plants ability to take up or metabolize pollutants to less toxic substances. The uptake of these pollutants by plants dependent on the plant species, level of the pollutants, hydrophobicity, solubility, and polarity. Fairly hydrophobic organic compounds can be easily absorbed and translocated by the plants. However, soluble compounds cannot be absorbed into the roots or translocated within the plant (Schnoor *et al.*, 1995). Whereas, hydrophobic compounds will get bound to the root surfaces or partitioned into roots, which cannot be further translocated within the plant (Schnoor *et al.*, 1995; Cunningham *et al.*, 1997). Non polar molecules of molecular weights <500 will be absorbed into the root system. In contrast, polar molecules will easily enter into the root system and get translocated. The uptake, accumulation and degradation of contaminants vary from plant to plant. As shown in Figure 1, the main phytoremediation technologies are: phytostabilization, phytoexctraction, rhizodegradation, rhizofiltration, phytodegradation, and phytovolatization.

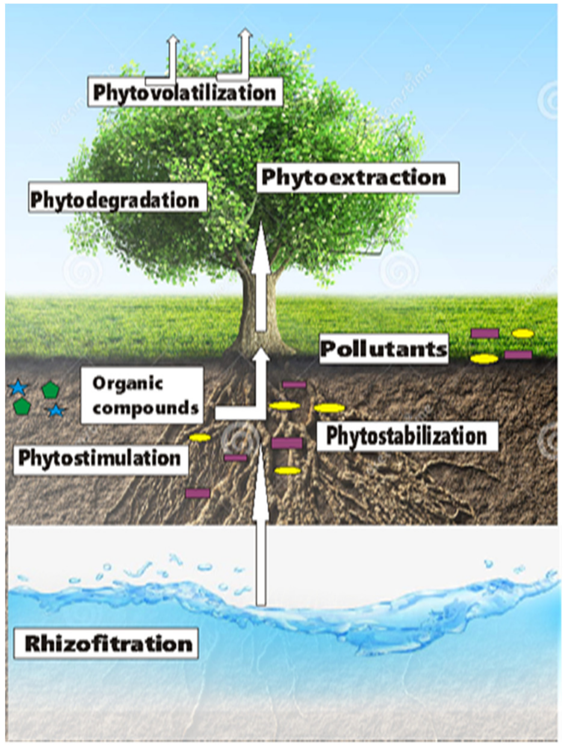

Figure 1. Phytoremediation technologies exhibited by plants

Phytoextraction

Phytoextraction is also known as phytoaccumulation, and is the most common phytoremediation technology, which involves the uptake of contaminants from the soil via the plant roots followed by storing the same in the plant stem or leaves. The phytoextraction technology requires the translocation of heavy metals from the roots to the harvestable shoots. The translocation of metals by the plants required the following conditions: (a) the metal must be soluble, (b) the roots of the plant have to absorb the metal, (c) the metal has to be chelated by the plant, (d) the chelated metal is then translocated by the plant. Finally, the plant must be able to adapt to any damages the metal might cause. Once a metal is taken up by absorption, it binds to the cell wall of the plant root (Han *et al.*, 2006). After the absorption of the metal, the metal can be alone or sequestered by a chelating agent or another compound (Clemens *et al.*, 2002). This metal then has to go through the root via symplastic pathway to reach the xylem. Heavy metal such as Pb, exist in form of insoluble carbonates, hydroxy-oxides and phosphates precipitates, which are mostly unavailable for uptake by the plant, leading to binding and immobilization in the soil matrix, and therefore restricting substantially the potential for phytoaccumulation of the metal. For this issue to be addressed, several attempts have been made in testing various chelating agents to enhance the phytoextraction of such harmful metals (Pb and Cd) in an induced phytoextraction.

The two basic strategies of phytoaccumulation are: (1) induced and (2) continuous phytoaccumulation (Salt *et al.*, 1998). Induced phytoaccumulation involves chelate-mediated release of bound metals into soil solution and thereby translocating the metals to the harvestable shoot (Salt *et al.,* 1998). Metals transport to the shoots as mediated by chelate seems to take place through transpiration stream in xylem sap. Inside the plant, the metal as a metal-chelate complex that moved from the roots to the shoots where evaporation of water takes place while the metal-chelate complex remains (Salt *et al.*, 1998). Chelate-assisted phytoextraction is applicable to a broad range of heavy metals. The most commonly used chelating agent or surfactant are: Citric acid, EDTA (ethylene diamine tetra acetic acid), EGTA (ethylene glycol-O,O′-bis-[2-amino-ethyl]-N, N′,-tetra acetic acid), CDTA (1,2-Diaminocyclohexanetetraacetic acid disodium salt solution), DTPA (diethylenetriaminepentaacetic acid), EDDHA (ethylenediamine di o-hydroxyphenyl acetic acid), and NTA (Nitrilotriacetic acid) (Robinson *et al.*, 2004; Huang *et al.*, 2005). Also, organic fertilizer may also be used to improve the bioavailability of heavy metals in soils (Oseni *et al.*, 2015; 2018).

In continuous phytoaccumulation, the plants used are genetically modified in such that they have unique genes that are capable to accumulate heavy metals (Kotrba *et al.*, 2009). When these plants are grown in soils rich in heavy metals, they are capable to translocate, accumulate and tolerate high amounts of these heavy metals in their tissues (Kotrba *et al.*, 2009; Tangahu *et al.*, 2011). Hyperaccumulator are those plant species which can accumulate metals to exceptionally high concentration in their shoot (Brown *et al.*, 1995; Reeves and Baker, 2000). Hyperaccumulation plants will accumulate more than 10 $mgkg^{-1}$ of Hg, 100 $mgkg^{-1}$ of Cd, 1000 $mgkg^{-1}$ of Pb, Cu, Cr and Co and 10000 $mgkg^{-1}$ of Ni and Zn (Ma *et al.*, 2001). For example, *Thlaspi caerulescens* which belong to the member of Brassicaceae, had been reported to be a hyperaccumulator of Zn. It can accumulate Zn up to 26000 $mgkg^{-1}$ without showing any symptoms of toxicity (Baker *et al.*, 2000). This plant, can also extract up to 20% of soil exchangeable Cd from contaminated sites (Brown *et al.*, 1995; Yanquu *et al.*, 2004). *Pteris vittata,* which is a fern, has also been discovered to be hyperaccumulator of As. It had been shown to accumulate as up to 14500 $mgkg^{-1}$ in fronds without showing symptoms of toxicity (Brown *et al.*, 1995). In addition, *Alyssum bertolonii,* has been found to phytoremediate Ni and can bioaccumulate Ni at levels as high as 1%, which is over 100-1000 times higher than other plants (Gerrard *et al.*, 2000). Nevertheless, the phytoextraction potential in most hyperaccumulators is limited because of their slow in growing and small biomass (Li *et al.*, 2003).

Therefore, preference is given to plants that can yield larger dry biomass when raised on soils contaminated with heavy metal over popular hyperaccumulators that may contain appreciably higher concentrations of heavy metal in them. For instance, *Brassica juncea,* though bearing one-third Zn concentration, it is more effective at the removal of Zn from the soil than *T. caerulescens* - a well-known Zn hyperaccumulator - as *B. juncea* produces much more biomass than *T. caerulescens*. Further study using classical or molecular genetic methods is expected to give some plants the opportunity to accumulate heavy metals (Boyd and Martens, 1992). In plants, genes coding for metal transport systems have been recognized and are expressed in the hyper-accumulating species and non-hyper-accumulating species of plant. Several pieces of evidences show that genes coding for heavy metals transport systems are invariably over-expressed in hyper-accumulating plants exposed to heavy metals (Schmidt, 2003; Misra *et al.*, 2009). Genetic evidence indicates that hyper-accumulators metal transport systems are overdeveloped. This could be to accelerate the root-to-shoot process and limit the period of metal exposure to plant systems before the storage of the metal. Table 1 showed the phytoextraction of heavy metals and plants used.

Phytovolatilization

Phytovolatilization involves the uptake of contaminants from the soil through the root and transforming them into less toxic volatilized form before releasing the same to the atmosphere through the stomata (Rascio and Navari-Izzo, 2011). Volatilization in plants is a technology whereby the contaminants are moved to air spaces of the plant vascular system and later diffused into the ambient air. The contaminants being released by the plant into the ambient air are considered to be less toxic. Volatilization activities of plants had been recorded for a number of contaminants, both inorganic and organic. The mechanism of emission of organic compounds that are absorbed by the roots, partly transformed and transported by the activities of xylem into the shoot is important in phytoremediation because it is suitable for eliminating volatile compounds in the shallow ground water contamination. Certain contaminants like As, Se, and Hg exist in the environment in the form of gases (Amold *et al.*, 2007). Recent studies have attempted to find naturally occurring or genetically modified species of plants that can absorb these contaminants from the soil in their elemental forms, biologically convert them inside the plant, and release them to the atmosphere in form of gases (Sakakibara *et al.*, 2007).

Table 1. Plants used for phytoextraction

Common name	Botanical name	Metal(loid)	Reference
Sunflower	*Helianthus annuus*	Pb, Zn	Odoh *et al.* (2019)
Canola	*Brassica napus*	Cd, Cu or Mn	Cherian and Oliveira (2005)
Indian mustard	*Brassica juncea*	Pb Cd, Se, Mn, Cu, Zn	Cherian and Oliveira (2005)
Willow	*Salix viminalis*	Pb, Cd, Ni	Misra *et al.* (2009)
Alpine pennycress	*Thlaspi caerulescens*	Zn, Cd,	Cherian and Oliveira (2005)
Common ragweed	*Ambrosia artemisiifolia*	Pb	Cherian and Oliveira (2005)
Herbis mundi	*Arabidopsis helleri*	Cd	Nriagu and Pacyna (1988)
Sedges	*Carex hirta*	Pb Cd, Mn, Cu, Zn	Brunetti *et al.* (2011)
Rushes	*Juncus effuses*	Pb Cd, Mn, Cu, Zn	Brunetti *et al.* (2011)
Reeds	*Phragmites australis*	Pb Cd, Mn, Cu, Zn	Krämer (2005)
Cattails	*Typha latifolia*	Pb Cd, Mn, Cu, Zn	Krämer (2005)
Swollen duck weed	*Lemna gibba*	As	Krämer (2005)
Shrub tobacco	*Nicotiana glauca*	Zn, Pb, Cd, Ni, B	Krämer (2005)
Chinese brake fern	*Pteris vittata L.*	U, As	Krämer (2005)
vetiver	*Vetiveria zizanioides*	Cu, Zn, and Pb	Brunetti *et al.* (2011)
Oilseed rape	*Brassica napus*	Cr, Cu, Pb and Zn	Brunetti *et al.* (2011)
Green amaranth	*Amaranthus h*ybridus	Pb, Hg, Cd, Ni	Chunilall *et al.* (2005)
Bitter gourd	*Momordica charantia*	Pb	Oseni *et al.* (2015)
Siam weed	*Chromolaena odorata*	Pb	Oseni *et al.* (2018)
Wireweed	*Sida acuta*	Pb	Oseni *et al.* (2018)

Phytovolatilization technology is particularly attractive for the remediation of as Seselenium, Agsilver, Asarsenic, chlorinated solvents and Methyl tert-butyl ether in the environment (Suszcynsky and Shann, 1995; Dushenkoy *et al.*, 2002). This technology has been considered effective for the removal of These volatized contaminant. Phytovolatilization investigation effort in the past often failed as a result of the analytical method and high detection limit. However, sensitive methods such as radioactive labeling are now used in the volatilization of toxic compounds (Suszcynsky and Shann, 1995; Amold *et al.*, 2007). This technique only detected the total amount of pollutants being volatilized as a result of the labelled compounds, but showed little or no information on the mechanism involved. Transpiration is the primary means of removing the contaminants followed by diffusion to ambient air via the tissues. The contaminant is taken up by the plant, eventually modified, and released by the leaves into the atmosphere through the pathway of the evaporation subset known as transpiration (Amold *et al.*, 2007; Sakakibara *et al.*, 2007). For example, methyl *t*-butyl ether (MTBE) which is soluble and volatile contaminant. This contaminant can be easily moved with water, whereby the large amount is transpired and volatilized from the foliage and through the stem and root diffusion (Brown *et al.*, 1995; Limmer and Burken 2015). The movement of MTBE into and through *Medicago sativa* had been demonstrated and characterized, and also its distribution within the soil under various evapotranspiration conditions (Brown *et al.*, 1995). The phytovolatilization potential of plants such as herbaceous species, trees, shrubs, wet-land species had been studied (Limmer and Burken, 2015). Recently, work has been done to insert bacterial Hg ion reductase genes into plants such as, *Nicotiana tabacum* and *Arabidopsis thaliana* for Hg phytovolatilization (Davis *et al*., 2001). According to Rugh *et al.* (1998), *Liriodendron tulipifera* plantlet had been found to volatile Hg effectively. Also, *Brassica napus* can volatize and accumulate Se (Meagher *et al*., 2000). *P. vittata* effectively volatilizes As, it can remove up to 90% of the total uptake of As from As-contaminated soils, from the experiment performed in greenhouse. However, the mechanism of the volatilization of As by *Pteris vittata* remains unknown (Amold *et al*., 2007).

Rhizofiltration

Rhizofiltration is also known as phytofiltration, is a technique used for the removal of heavy metals or contaminants from the surface of the water, waste-water or extracted ground water through precipitation or adsorption onto the plant roots, or absorption into the roots (Bañuelos *et al*., 1997). Rhizofiltration is used to decontaminate groundwater. The contaminants maybe absorbed by the plant roots and remain within the root system, or translocated to the shoots. These phenomena depend on the contaminant, concentration, and the plant species involved. In another way, the contaminants can form precipitation at the rhizosphere or the water body as a result of the root exudates and changes in hydrogen ion concentration of the rhizosphere (Abubakar *et al*., 2014). The similarity between rhizofiltration and phytoextraction is that both result in the accumulation of contaminants in the plants (Abdullahi, 2015). But in rhizofiltration, plants are used in phytoremediation contaminated ground water instead of soil and the experiments are carried out in the greenhouse (Abdullahi, 2015). And the water used for the experiment can be self-contaminated or collected from the waste site. During the experiment, the plants are harvested to determine their phytoremediation potentials after the roots have become saturated.

Various aquatic plant species have been found effective in the removal of toxic metals such as $Zn^{2+,}$ Cu^{2+}, $Cd^{2+,}$ Cr^{6+}, $Ni^{2+,}$ Mn^{2+}, Pb^{2+} and also, radioactive (radionuclides) contaminants from aqueous solutions. Aquatic plants found suitable for phytofiltration are: *Pistia stratiotes* (Anderson *et al*., 1993), *Spirodela polyrrhiza* (Anderson *et al.,* 1993), *Myriophyllum aquaticum* (Zayed *et al*., 1998), *Ludwigina palustris* (Harguinteguy *et al*., 2013), *Mentha aquatic* (Anawar *et al.,* 2008), *Eichhornia crassipes* and *Centella asiatica* (Zurayk *et al*., 2003). Moreover, terrestrial plants such as *Brassica juncea* (Mokhtar *et al*., 2011) and *Helianthus annuus* (Raskin and Ensley, 2000) are more preferred than aquatic plants in phytofiltration because their great biomass and longer, faster-growing root systems than aquatic plants.

Phytostimulation

Phytostimulation is also referred to as rhizodegradation or enhanced rhizosphere biodegradation, plant assisted bioremediation or degradation. This Phytoremediation technology involves the breaking down of organic contaminants in the soil through the activities of microorganism in the plant root zone or rhizosphere. The presence of the plant root increases the population of the microorganism by the exudates produced by the root such as carbohydrates, sugars, amino acids, acetates, nucleotides, fatty acid, flavanone and enzymes (Dushenkov *et al*., 1995) or the root system bring oxygen to the rhizosphere which enhanced aerobic transformations. Also, mycorrhizae fungi associated with plant root can also perform rhizodegradation. Organic contaminants such as polycyclic aromatic hydrocarbons (PAHs), petroleum hydrocarbons, pesticides, chlorinated solvents, toluene, polychlorinated biphenyls (PCBs), xylenes, benzene, and ethylbenzene had been successfully degraded (Shimp *et al*., 1993). Some of these organic contaminants can be broken down into smaller products, or directly mineralized to inorganic products such as water and carbon dioxide.

In recent times, a lot of research has been done using the rhizodegradation technology. According to Kaimi *et al.* (2007), rhizodegradation in diesel-contaminated soil under different soil conditions, noticed significant decrease in total petroleum hydrocarbon (TPH) using *Lolium multiflorum* with enhanced microbial activity in the rhizosphere. Also, Hoffman and Nelson (2003) found out that *Salix lasiolepis* can also be used for phytostimulation of hydrocarbon -contaminated groundwater. Moreover, pot-culture experiment was conducted by Poornachander *et al.* (2017) for rhizodegradation of PAHs using *Vigna mungo* and *Bacillus. cereus* CPOU13, and the result showed that a high concentration of PAHs was degraded around the rhizosphere of the plant and the bacterial population was also increased. Other plants used for rhizodegradation are: *Zea may* (maize) (Poornachander *et al.*, 2017), *Cynodon dactylon* (Bermuda grass) (Xu *et al.*, 2006; Hutchinson *et al.*, 2001), *Kochia species* (Merkl *et al.*, 2005), *Oryza sativa* (Anderson *et al.*, 1994) and legumes such as *Lespedeza cuneate*, *Glycine max*, *Pinus taeda* (Hoagland *et al.*, 1994).

Phytostabilization

Phytostabilization is a technology that involves the use of the plant to immobilize the contaminants in the soil through accumulation into the root, adsorption onto the root surface or precipitation within the root zone thereby preventing their movement in the soil (Anderson and Walton, 1995; Munshower *et al.*, 2003). Heavy metals phytostabilization occurs due to precipitation, sorption, metal valence reduction or complexation (Mendez and Maier, 2008). Phytostabilization efficiency is based on the soil amendment as well as the plant used (Pierzynski, 2002). This technology prevents man's direct contact with the pollutants and also, it provides surfaces for metal sorption and precipitation (Jadia and Fulekar, 2009). Whereas, the major disadvantage of phytostabilization is continuous monitoring of the contaminant in the environment because of their presence in the soil and constant augumentation of the soil in order to stabilize the contaminants (Jadia and Fulekar, 2009).

The soil microorganisms/or adding amendments such as phosphates, organic matter, biosolids, and alkalizing agents played an essential role in the achievement of phytostabilization. Madhaiyan *et al.* (2007) inoculated endophytic bacteria (*Magnaporthe, oryzae,* and *Burkholderia sp.*) with *Solanum lycopersicum* grown in Ni and Cd polluted soil. And the result showed that the association of the bacteria increased the plant growth but prevented the accumulation of the heavy metals in the roots and shoots of the plant and also their bioavailability in the soil. According to Oseni *et al.* (2015), working on *Momordica charantia* with amended soil of organic fertilizer grown in Pb polluted soil. From the experiment, Oseni *et al.* (2015) discovered that *M. charantia* medicinal plant is safe for herbal used because the Pb did not bioaccumulate in the plant but phytostabilized the contaminant with good growth. Also, Pilon-Smits (2005) worked on a combination of trees and grasses for the phytostabilization of metals and found out that the grasses do not accumulate the metals in their shoots which prevent grazing animals in exposure to toxic contaminants. Other plants used for phytostabilization are: *Solenum nigrum* and *Spinacia oleracea* used to stabilize Re (Pilon-Smits, 2005), *Amaranthus spinosus* used to stabilize Cu, Pb and Cd (Tzvetkova and Bozhkov 2009), *Clerodendrum indicum* for Fe (Chimayee *et al.,* 2012), *Jatropha curcas* for Zn and Fe (Mukherjee *et al.*, 2013), *Zea mays* for Cd (Abioye *et al.*, 2010), *Riccinus Communis* for Ni (Redjala *et al.*, 2011) and *Salix jiangsuensis* CL 'J-172' and *Salix babylonica* for Cu (Adhikari and Kumar, 2012).

Phytodegradation

Phytodegradation is also known as phytotransformation, which involves the breaking down of contaminants taken up by plants through metabolic processes. Or breaking down of contaminants that surround the root of the plant by the effects of enzymes produced by the plant roots which increased the rate of degradation. These pollutants that are broken down into the smaller unit, are then taken up by the plant to improve their growth (Chen *et al.*, 2012). In phytotransformation or phytodegradation, the plant root is not dependent on the microorganisms associated with the rhizosphere for the degradation rhizosphere biodegradation. Contaminants commonly degraded by plants are: munitions, chlorinated solvents, herbicides, insecticides, toluene, ethyl benzene, benzene, xylene and inorganic nutrients. The uptake of these chemicals into the plant tissue is also dependent on the uptake efficiency, transpiration rate as well as concentration of the contaminants in soil water (Zayed and Terry, 2003). In phytodegradation, dehalogenase, laccase, nitroreductase, nitrilase and peroxidase are the most commonly produce enzymes by the plant roots (Schnoor *et al.*, 1995). Moreover, nitroreductase has been discovered in algae, mono-cots, dicots, ferns, and trees (Johnsen *et al.*, 2005).

Petrochemical sites, landfill leachates, fuel spills, agricultural chemicals, and oil storage area can be reclaimed by phytodegradation (Zayed and Terry, 2003). For this technology to be successfully implemented, it is required that the compounds that are transformed and accumulated in the plant should be non-toxic or substantially less harmful than the parent compounds. Phytotransformation, in certain cases, may be applied as a polishing treatment or combined with other remediation technologies. Degradation of contaminants by plant produced-enzymes can take place in a microorganism-free environment. Different of plants have been used extensively in the degradation or transformation of contaminants. *Myriophyllum aquaticum* (an aquatic plant) and the *Nitella* (algae stonewort) have been utilized to degrade trinitrotoluene (TNT). Trichloroethylene (TCE) degradation has been reported in *Populus tremula* and in *Populus tremula* cell cultures, leading to metabolites production and complete mineralization of a little component of the TCE applied (Gordon *et al.*, 1997). *Populus tremula* (*Populus deltoides* × *nigra* DN34, Imperial Carolina) had been used for atrazine degradation. *Populus tremula* have also been used to remove nutrients from groundwater (Burken and Schnoor, 1993). *Taxodium distichum*, *Liriodendron tulipifera*, *Salix nigra*, *Betula nigra*, *Quercus viginiana*, and *Quercus falcata* were able to support some degradation of the herbicide bentazon. The processes of transformation by plant differ, depending on the nature of the contaminant, plant species and tissue type. These processes can be categorized as oxidation, reduction, conjugation and sequestration. Plants synthesizes a large number of enzymes during their primary and secondary metabolisms, which are useful for phytodegradation (Rasalingam *et al.*, 2014).

Soil augmentation

Phytoremediation technology required augmentation (Oseni *et al.*, 2018). Ethylene diamine tetra acetic acid (EDTA) and fertilizer are examples of chemical augmentation while arbuscular mycorrhizal species are examples of a bioaugmentation. Appropriate augmentation of metal hyperaccumulator plant may not only shield the plants from the potential effect of the stress of pollution but also enhance the efficiency of the phytoremediation potential of the plant. However, augmentation of heavy metals through microbes is better than chemically-induced ones. This is necessary in order to avoid the negative impact of chemical augment on the environment. Beneficial symbionts that are associated with the roots of higher plants by a symbiotic association, assisted plants in the uptake of nutrients along with heavy metal binding (Conger and Portier, 1997). Arbuscular mycorrhizal fungi (AMF) had been demonstrated to alleviate the stress of heavy metal in plants (Turnau *et al.*, 2006). Chemically-mediated or chemoaugmentation and microbially-mediated phytoremediation or bioaugmentation strategies.

Chemically-induced metal removal by plant species

Chelating agents, like citric acid, ethylene diamine tetra acetic acid (EDTA), ethylene diamine disuccinate (EDDS), ethylene glycol-O,O′-bis-[2-amino-ethyl]-N, N′,-tetra acetic acid (EGTA) and ethylenediamine di o-hydroxyphenyl acetic acid (EDDHA) have been discovered to enhance metal removal by plant species by mobilizing metals and accumulation (Ma *et al.*, 2001; Seneviratne *et al.*, 2017). Various fertilizer types in the form of organic and inorganic can also be applied as chelators in induced phytoextraction processes (Zhang *et al.*, 2015; Alaribe and Agamuthu, 2015). According to Ali *et al.* (2013) chelates had been used to enhance plants to remove heavy metals from the contaminated site. The contaminants being removed include: Ni, Cd, Pb, Cu, and Zn. According to the following authors, Huang *et al.* (1997), Smolinska and Szczodrowska (2016) suggested that chelates are able to increase Pb accumulation in agronomic crops such as *Zea mays* and *Pisum sativum*. In the results of Huang *et al.* (1997), Pb accumulation increased by one thousand times, and this occurred after the application of Hyroxyethyl Ethylenediamine Triacetic acid (HEDTA) when compared with the control. In these conditions, there was a rise in Pb concentrations in plant shoots from below 500 $mgkg^{-1}$ to above 10,000 $mgkg^{-1}$ one week after the application of HEDTA.

Microbially-induced heavy metal removal by plant

This involves the application of microbial species to stimulate remediation capability of the plant to alleviate the stress of toxicity during the processes of removing metals. According to Turnau *et al.* (2006), microbes at the rhizosphere are used because of the direct influence they have on the growth of plants. *Arthrobacter* and *Pseudomonas species* of microbes at root zone that are capable of producing organic chemicals that stimulate plant growth under stress. In addition, nitrogen-fixing bacteria that belong to the genera *Rhizobium, Azorhizobium and Bradyrhizobium* also engaged in phytoremediation of heavy metal from the environment. Another mutualistic relationship between plants and microbes that are exploited widely to alleviate pollution of from the environment is mycorrhizae. About 92% of the plant families are associated with mycorrhizae. Arbuscular mycorrhizae (AM) is the ancestral and the most prevalent symbiotic association found in the plant kingdom. Many authors had reported isolating spores of arbuscular mycorrhizal fungal taxa such as *Gigaspora* and *Glomus* associated with most of the plants grown in heavy metal polluted environment (Turnau *et al.*, 2006). Prasad *et al.* (2003) reviewed a calamine spoil mound rich in Cd, Pb and Zn in Poland and retrieved *Glomus spp* and *Entrophospora spp.* spores from the mycorrhizospheres of the plants growing on the soil. Seneviratne *et al.* (2017) reported that mycorrhizae may be serving a crucially important purpose in providing protection from heavy metals to plant roots. However, the efficiency of protection varies between different heavy metals and distinct isolates of mycorrhizal fungi. Sarma *et al.* (2017) reported that, extra-radical hyphae of arbuscular mycorrhizae fungus *Glomus mosseae* can transport Cd from soil to *Trifolium hybridum* grown in pots, but that transfer from fungus to plant is restricted due to fungal immobilization.

Conclusions

Environmental contaminants have been a great threat to the living organisms and their environment. In order to prevent further deletion of the environment, a lot of researchers have focused on phytoremediation. Therefore, this paper reviews different environmental contaminants, phytoremediation technologies, and strategies, mechanism, augmentation and plants utilized. Moreover, the review helped us to understand which phytoremediation technology to be used for a particular contamination in the environment and the need for augmentation. Based on this, the efficient use of plants for phytoremediation will be possible.

Authors' Contributions

All the authors work intensively on each of the phytoremediation technology and contributed to the final manuscript proofreading. MS, AA, E.D, AM, OE, and GO work on phytovolatilization, rhizofiltration, phytoextraction, phytostabilization, need for bio-augumentation, and phytodegradation respectively. OM works on introduction and phytostimulation, as well as writing the review and editing.

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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