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Phytoremediation: A Preeminent Alternative Method for Bioremoval of Heavy Metals from Environment

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ABSTRACT

Phytoremediation is considered as a cost-effective and environmentally friendly technique for decontaminating environments that have been contaminated with heavy metal ions. The technique describes the use of plants and their concomitant microbes to mitigate environmental contaminations. However, conventional remediation techniques like chemical, thermal and physical treatment methods are too costly, and may end of causing more contamination to the environment. Phytoremediation practice provides a major information on the utilization of plants and their materials in decontaminating polluted environments. Heavy metals and other organic contaminants are among the most precarious substances released into the environment which have an eminent level of toxicity and sturdiness of both aquatic and terrestrial organisms. The review aimed at providing a broad understanding of utilizing various plants and their materials in decontaminating polluted environments with heavy metals and other organic contaminants. It also provided the general methods used in treating the aforementioned contaminants in an environment. The review further discussed the classes of phytoremediation like phytoextraction, phytovolatilisation, phytostabilization, phytotransformation, phytodegradation and phytofiltration. The generalized advantages and disadvantages of phytoremediation were ultimately highlighted.

1. Introduction

Phytoremediation could be viewed as the utilization of green plants to remove or reduce the amount of metal ions and other contaminants from any polluted environment [1]. The word “Phytoremediation” coined from Greek and Latin words. “Phyto” from Greek “phutón” meaning plants, while “remediation” from Latin “remedium” meaning a medicine, remedy, cure or restoring balance. Therefore, the word is describing the technology for the treatment of environmental

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problems by means of using plants and their concomitant microbes to mitigate or lessen the environmental problems with a devoid of excavating the contaminants and dispose them somewhere else [2]. Phytoremediation propositions a cost-effective and an environmentally friendly technique for decontaminating waters and soils that have been contaminated with heavy metals [3], due to the fact that the conventional remediation techniques like chemical, thermal, physical and other treatment methods are costly, and may cause more contaminations to the environments [4].

The pollution of the biosphere, particularly soil and water bodies are getting substantial communal attention due to the magnitude and accelerated discharges of the heavy metals and other contaminants via industrial activities [5], municipal wastes [6, 7], irrigation, fishing and hydro-power generation [8]. The Heavy metals are among the most precarious substances when discharged in an environment due to their elevated level of toxicity [5]. The Environmental Protection Agency (EPA), United States conducted a research that revealed that heavy metals were the most eminent contaminants in the three hundred and ninety five (395) remedial action places in the United States [9].

Nonetheless, the mobility of the metals in an environment is contingent on their speciation, and they are usually present in the transferable situates of the soil matrix [10] For example, Cadmium salts like sulfides, oxides or carbonates are water insoluble. However, they can be transformed to soluble salts under the influence of acids and oxygen [11]. More so, Cadmium is greatly mobile in the soil-plant system and could be accumulated in plants without causing much toxic effect on the growth of the plant [2], which could be due to formation of Phytochelatin, a metal binding peptide that helps in the detoxicating the aggregated metals [12].

2. General effects of Various Heavy Metals in Plant Species

The general effects of various metal ions in plant are provided by Gardea-Torresdey *et al.*, [12]. Their findings revealed that high concentration of; Cadmium (Cd^{2+}) in plants decreases the germination of seeds and plant growth, which ultimately lowers the lipid contents of the plants. However, accumulation of Cadmium in certain plants convinces the production of a metal binding peptide, Phytochelatin. This substance plays a vital role in plants by detoxificating the accumulated Cadmium; Mercury (Hg^{2+}) also known as quicksilver facilitates the accumulation of carbolic acid, phenolics. Phenolics are among the aromatic benzene compounds that are formed by the plants for stress safeguarding. It equally helps in the development of plants with regards to the biosynthesis of pigment and lignin [13].

Conversely, mercury in plants not only reduces the plant water uptake, but also lowers the photosynthetic activities of the plant; Lead (Pb^{2+}) in plants was reported to upturns the formation of an enzyme (superoxide dismutase) that interchangeably fast-tracks the superoxide radical dismutation into either hydrogen peroxide or oxygen molecule. But on the other hand, Pb^{2+} retards the production of chlorophyll and growth of the plants; Chromium (Cr^{3+}) in plants facilitates the decrease in the activities of some enzymes responsible for plant growth, which incur the damage of the membrane and roots that eventually resulted into plant chlorosis, a condition that causes an unusual retard or complete loss of the plant normal green coloration of their leaves; Copper (Cu^{2+}) in plants alters the plant growth and at the same time disrupts its reproductive and photosynthetic processes. Cr in plants was equally reported to diminish the surface area of thylakoid, a membrane-bound cubicle within a plant's chloroplast and it's responsible for photosynthetic light-dependent reactions; Nickel (Ni^{2+}) in plants fast-tracks the reduction of chlorophyll, protein and enzyme production, and accumulation of dry mass. However, Ni^{2+} upsurges the amount of free amino acids that motivates the plant metabolic activities; Zinc (Zn^{2+}) in plants helps lowers the toxicity of Ni^{2+} thereby improving the ability of seed germination. Zn^{2+} equally supports the growth of plants, at the same time, it raises the ratio of ATP-Chlorophyll to a tolerable amount [12].

3. Treatment Methods for Heavy Metals Contaminated Sites

The intrusion and interference of humans with the environment have resulted in the contamination of soil. The contaminated soil will continue to post various problems to the environments, hence the need to provide some means of either reducing their amount or total removal from the contaminated sites. There were four (4) different options for the treatment of soils that have been contaminated with metal ions. The first is to control the exploitation of the land, thereby allowing the contamination as it is; the second is to excavate the contaminated sites, followed by filling of the land; the third is to partially or completely encapsulate the contaminated sites; finally Ex Situ or In Situ treatment of the contaminated sites [14]. However, in recent days basic remediation techniques to mitigate contaminants have been intensively reviewed. The most popularly employed methods include; Physical, Chemical, Thermal and Biological processes [14]. Though, first-three above highlighted methods are not highly efficient, because they could eventually roll down to cause water and air pollution. As such, phytoremediation technique was reviewed and reported promising because it's cheap and environmentally friendly.

3.1 Physical Method
3.1.1 Isolation and containment

This is one of the physical treatment methods of decontaminating polluted sites, during which some set of barriers made of cement, bentonite, steel and other rainproof supplies are being employed for isolating and containing the contaminants so as to impede their movement or to lessen the permeability of the contaminants to a rate less than $1{\times}10^{-7}$ m/s, which is the ambit or boundary recommended by the EPA, US. Capping is another technique, which is site specific that thwarts water penetration into the soil, thereby improving the efficiency of the decontamination [15].

3.1.2 Soil washing

This is among the physical treatment techniques that are extensively utilized for effective and efficient remediation of soil contaminated with either organic contaminants or heavy metals. This method is used for the soils in which contaminants are accumulated in the fine fraction of the soil matter. This process removes contaminants by dissolving or suspending them in the wash solution [14].

3.2 Chemical Method
3.2.1 Chemical extraction

This technique employed in the use of an extracting chemical to excerpt and extract the contaminants from the contaminated soil into the chemicals. The technique could be utilized for both organic compounds and heavy metals. The extraction method could efficiently be viewed in to ways; Acid extraction, this employs the use of various acid types, like sulphuric acid and hydrochloric acid, to remove the contaminants, and it's mainly used to decontaminate environments or locations polluted with heavy metals; Solvent extraction, this utilizes the use of some organic solvents, like *Di-2-ethylhexylphosphoric* acid (D2EHPA) and Tributylphosphate (TBP), to extract the contaminants, and it's mainly used to remove organic contaminants from the polluted environments [16]. Since bits of solvents could be retained in the soil during the treatment, understanding the toxic nature of the solvents is highly crucial [14].

3.2.2 Chemical redox process

This process involves the use of Reduction or Oxidation reactions to transform the contaminants into harmless or less toxic composites that are less mobile or inert and, at the same time, more stable. Some of the most frequently used oxidizing agents include; hydrogen peroxide, ozone, chlorine, hypochlorites and chlorine dioxide. This technique is mainly used for the treatments of an environment polluted with metals, and can be greatly accomplished either at the contaminated sites (in situ) or Excavate the contaminated site and treated elsewhere (ex situ). For the in situ processes, the chemical agents for the redox reaction must be selected with utmost care to prevent further contamination of the soil with these chemicals [17, 18]. More so, contingent on the contaminant concentration, the cost of this method varies [15].

3.3 Thermal Method

This technique of treatment employed the use of thermal process for the adsorption of the contaminants. The technique facilitates the separation of volatile contaminants from the contaminated environment. It is normally an ex-situ treatment method, during which the contaminated site is subjected and heated to a very elevated temperature. By that, all volatile contaminants, mostly organics, will be separated from the contaminated sites [19, 14]. One of the major setbacks of this method is the emission of air alongside with the volatile contaminants. However, it could be minimized during their capturing and separation [19]. Thermal methods can be viewed, based on the operating temperature, into High temperature arrangements which operates at temperatures above 1000 0F and the systems could bring about a thorough destruction of the contaminants due to the establishment of the oxidation at higher temperature of thermal system; and low temperature arrangements, which operates at a temperature lower than 1,000 0F, and the method was reported to upsurge the phase transfer rate, which equally facilitates the partitioning of contaminants from the contaminated sites [20].

3.4 Electrokinetics

Electrokinetic technique for the treatment of contaminated environments involves the process of passing an electric current of low intensity between the anode and cathode that are imbedded in the environment, particularly soil. Consequently, small charged particles and ions are conveyed between the electrodes. Buffer solutions are, therefore, used in the electrodes in order to keep up a constant pH at the electrode [21]. The accumulated metals at the electrode can easily be detached by precipitation or electroplating [22]. This technique is mostly conducted Ex Situ, during which the excavated contaminated soils are treated elsewhere, and it can efficiently and effectively be conducted on soils that are low permeable [22, 15].

3.5 Bioremediation

Bioremediation is the process that involves the utilization of living organisms to lessen or eliminate hazardous chemicals accumulated in an environment [23]. The major organisms used include fungi, bacteria, algae, planktons, plants and protozoans. Both naturally occurring and genetically modified organisms can potentially be used [24, 25]. The organisms can annihilate organic chemicals, whereas the contaminated metals can either be directly removed or converted to a stable form [24]. More so, the treatment of contaminated environments, like soils, sludge, wastes and sediments, that are polluted with; organic contaminants resulted into the biodegradation of the organic substances into an innocuous outcome; toxic metals to the suspension, precipitation, equilibrium and recovery; and mostly targeted at capacity reduction, as well as contaminants stabilization. Consequently, numerous microbial techniques have recently been exploited to treat various contaminated environments [26]. The basic principles of bioremediation include biosorption [27], bioaccumulation [28], and biocrystalisation [29, 26].

4. Classification of Phytoremediation Technology

Phytoremediation has been classified based on the process by which plants are utilized to remove or lessen the toxic effect of contaminants from the contaminated environments [30]. The technology can broadly be classified into; Phytoextraction [31], Phytotransformation [32, 33], Phytostimulation [34], Phytostabilization [35], Phytovolatilisation [36] and Phytofiltration [37].

4.1 Phytoextraction

Phytoextraction, also referred to as phytoabsorption, phytosequestration, or phytoaccumulation, is one of the best used techniques of phytoremediation that involves majorly the use of contaminant-accumulating plants to confiscate perilous compounds or elements, particularly heavy metals that may be noxious to microorganisms even at minuscule concentrations, from contaminated environments [38]. This technique is feasible and practicable commercially, during which the potential plants eradicate the metals by concentrating them at their harvestable fragments [39].

The phytoextraction technique comprises of two (2) broadly strategies which has been proposed to decontaminate toxic metals from polluted sites. The first approach is the utilization of plant species that have been considered as metal hyperaccumulators [40]. These plant species, hyperaccumulators, have been revealed as potentially handy in an environment cleanup, particularly polluted soils and waters. They have the ability of absorbing seasonable quantities of the metals from the polluted sites without causing adverse effects from the phytotoxins [38], though they have a relatively limited extraction capability due to their lower biomass production per annum [35]. The hyperaccumulators were reported to have a metal accumulation value that surpasses the threshold proportion of the plant parts concentrations of 0.001 % (Mercury), 0.01 % (Selenium and Cadmium), 0.1 % (Lead, Copper, Cobalt, Nickel, Chromium and Aluminium) and 1 % (Manganese and Zinc) from the plant parts biomass, dry weight [38, 41]. Furthermore, more than four hundred (400) plant species suggested and reported as hyperaccumulators, but relatively few researches were established about their prospect as natural hyperaccumulators from a practical point of view [40]. However, it was demonstrated that Thlaspi caerulescens (also known as Alpine Pennygrass) is a fabulous Cadmium and Zinc hyperaccumulator, which could accrue and endure up to 100 mg/kg and 10,000 mg/kg of Cadmium and Zinc in their tissues respectively (in dry matter) with a devoid of displaying any toxic symptoms [41], while Viola baoshanensis is a good Cadmium hyperaccumulator from a moderately contaminated environments with such metals [38].

The second possible alternate approach is the utilization of plant species that have been considered as non-accumulators. These plants could either be high biomass or fast-growing that could be cultivated easily with the readily established practices of agronomy [13, 42]. The high biomass crops like Helianthus annuus (sunflower), Brassica juncea (Indian mustard) and Zea mays (Maize) were reported promising for heavy metal uptake [43], while high biomass trees like Populus species (poplars) and Salix species (willows) were equally revealed to have excessive potential for generating exertions in phytoextractions [44].

Another possible approach is the utilization of chemical metabolizing agents, chelators. The chelators such as *Ethylene-Diamine Di* (o-Hyroxyphenylacetic Acid) (EDDHA), *Diethylenetriaminepentaacetic Acid* (DTPA), *Ethylene Diamine Triacetic Acid* (EDTA) and *Hydroxyethylethylene-diaminetriacetic acid* (HEDTA) are added to the contaminated soils to to upsurge the metal uptake in plants, which could ultimately augment and boost the efficiency and effectiveness of the phytoextraction processes [45]. *Ethylene Diamine Triacetic Acid* (EDTA) was successfully applied to soil contaminated with Lead (Pb^{2+}), and thus upsurges and stimulates the release of lead to the soil solution in the environment with significant accumulations of the metals in plant tissues [43]. EDTA was added to a soil contaminated with a total of 2500 mg/kg of Lead, which tremendously upturned the Pisun sativum and Zea mays concentrations of Lead in their shoots from less than 0.5 g/kg to more than 10 g/kg. [37]. However, on-site (In Situ) application of the chemical chelates was reported to pose a menace of pollution in ground waters [42].

It is equally of paramount important to know that whenever the heavy metals get absorbed into the plant’s cells, they trigger or elicit the formation of peptide ligands like metallothioneins (MTs) and phytochelatins (PCs) [47]. The formed peptides then bind and form other complexes with the heavy metals, which is stable and hence neutralizes the toxic nature of the metal ions [13], and ultimately enhances their uptake by the plants.

4.2 Phytovolatilisation

Phytovolatilization is among the techniques of phytoremediation that involves majorly the use of plants to remove volatile organic carbons (VOC) and some few inorganic carbons that could exist in volatile forms like Arsenic, Mercury and Selenium ions [30]. The plants take up the contaminants from the environments during water uptake and convey them to their leaves, then transform them into a volatile form biologically to the atmosphere at relatively low concentrations [48]. The technique has essentially been utilized for the treatment of an environments contaminated with mercury (Hg^{2+}), during which the mercuric ion is transmuted into less noxious basic mercury.

Though, the major setback here is that there is a likelihood of recycling the released mercury to the atmosphere via precipitation and ultimately redeposit them nether again to the bionetwork [46]. However, it remains a topic of research whether the release of the elements via volatilization into the atmosphere is innocuous or detrimental [50]. It was documented that both accumulators and non-accumulators volatilize Selenium [50]. Cruciferae or Brassicaceae, ordinarily recognized as mustards or the cabbage family were reported of releasing 40 g haâˆ’1 day âˆ’1 of Selenium as different gaseous compounds, and Brassicaceae juncea was reported effective in volatilizing up to ninety five percent (95 %) of Mercury (Hg) from a contaminated environment. Though, most of the Mercury volatilization befalls from the plant’s roots, which could have unpredicted environmental consequences [13].

More so, biotechnological means using rDNA technology was employed via developing transgenic plants to transfer the genes of interest for environmental refurbishment. A strong neurotoxic agent like Methylmercury, is easily biosynthesized in most Mercury-contaminated environments. For instance, merA and merB are bacterial genes of mercuric reductase and organomercurial lyase respectively, and were reported of being transformed into Thale cress (Arabidopsis thaliana) purposely to produce a Genetically Modified Organism (GMO) which is proficient in organic mercury detoxification by transforming the toxic metal into volatile less noxious mercury element. These genes of interest were eventually expressed in the freshly transformed plants. Bacterial genes like that of mercury (Hg^{2+}) reductase have been transferred effectively into plants like tobacco, yellow poplar and Brassica [51].

However, the phytovolatilization has a major disadvantage of not absolutely eliminating the contaminants. The process only transfers the contaminants from one form to another (i.e from soil to the atmosphere), which could easily be deposited back to the ecosystem. As such, the technique was reported as being among the most controversial methods of phytoremediation [13].

4.3 Phytostabilization

This phytoremediation method utilizes the use of plants to lessen the mobility of contaminants (either metallic or organic contaminants) by immobilizing or precipitating them from the polluted sites, thus by lessening or avert their availability and relocation to ground water or ultimate entrance into the bionetwork [30]. During the process, contaminants, particularly those in the soil are immobilized by a number of hyperaccumulating plants via roots absorption and accumulation, followed by roots adsorption or precipitation at the root zones and the soil physical stabilization [37]. The technique is generally used to remediate contaminated sediments, soils and sludge, and it depends on the ability of roots to limit the bioavailability and mobility of the contaminants within the environments.

Moreover, the primary use of the plants is to diminish the volume of water percolation via the soil matrices, which could result in the perilous leachate formation and subsequent deterrence of soil erosion and channelling of the toxic metals to other sites. Formation of a compact root system stabilizes the soils and averts its erosion [52]. Due to the ability of the plant roots to efficiently bind to soil, green vegetation is highly supportive in soil erosion control. More so, the roots of the vegetation expedite the holding of a substantial amount of water that is transpired back to the atmosphere. The roots equally lessen the quantity of heavy metals moving into the water table and other water bodies [37, 53].

Also, in order to re-institute vegetation at locations where plants have been vanished or demolished as a result of the high concentrations of metals, plant species that are tolerant to the metals can be propagated, thus lowering the effective relocation of the contaminants via soil leaching, pollution of ground water, wind and the passage of the exposed apparent soil [54]. The metal-tolerant ability was developed by certain plant species during evolution, whereas others could inherently possess such ability [55]. The Metal accumulation by the plants is expressed and measured in terms of the Bio-concentration Factor (BF) or Accumulation Factor (AF) and Translocation Factor (TF) or Shoot: Root (S:R) ratio [56].

However, a research was conducted to evaluate the growth prospective of certain plant species on polluted locations and the result revealed that only those plants with great Bioconcentration factor and low translocation factor are efficient for phytostabilization [57]. The research further exposed that the phyla nodiflora was utmost proficient in Zinc and Copper accumulation in their roots, while Gentiana pennelliana was the highly efficient plant for phytostabilization in areas polluted with Zinc, Copper and Lead [57]. Synthetic and natural enhancements could be added to the polluted sites in order to improve their biological and physical features during the process of phytostabilization. Other practices to facilitate phytostabilization include; addition of compost to increase the content of organic matter, increment of water holding capacity, addition of vital growth nutrients, pH adjustment and reduction of heavy metal bioavailability [37]. The improve in the growth of Festuca arundinacea and Lolium italicum by adding compost has tremendously increase the reduction in the concentrations of both Zinc and Lead in their roots and aerial portions [61].

Conversely, the foremost drawback of this technique is that the contaminants remain unaltered in the soil. Due to the change in the soil conditions and the degradation of organic substance, there could be an incomplete and gradual discharge and leaching, consequenting in the distribution of the metals to the adjoining locations via soil erosion. Hence a consistent and steady monitoring or follow up activities are needed during the processes of phytostabilization so as to observe and monitor the heavy metal bioavailability, mobility and ecological influence [13, 52, 59].

4.4 Phytodegradation

Phytodegradation is the microbial breakdown of contaminants via plant metabolic processes, in ground water and rhizosphere, into smaller and simpler fragments that are incorporated or integrated into the tissues of plants. During the course of contaminant degradation, the metabolism of the plants facilitates the reduction of the contaminants through contaminants break down, transformation, volatilisation or stabilisation from the polluted ground water and soil [13, 60]. Generally, plants contain enzymes, usually reductases, dehalogenases and oxygenases that are responsible in breaking down and converting contaminants including chlorinated solvents like trichloroethylene and some herbicides. Bacteria, fungi, Yeast and various microorganisms ingest and digest organic materials like solvents and fuels [32]. Organic compounds' Phytodegradation has been reported by which Cr (VI), a toxic form of Chromium which was proficiently transformed into less toxic Cr (III) using halophytes [32, 62].

Furthermore, several microorganisms including both fungi and bacteria were reported of having the capability of transforming noxious metals to their lesser toxic conditions. For instance, Pseudomonas maltophilia strain (isolated from contaminated soil) was reported of catalyzing the conversion and precipitation of several noxious metal oxyanions and cations, while Aspergillus niger (the oxalic and acitric acid producer) was documented of transforming $Zn_3(PO_4)_2$, $Co_3(PO_4)_2$ and ZnO, insoluble inorganic metal composites into their corresponding insoluble metal oxalates [13, 62, 63].

4.5 Phytofiltration

Phytofiltration encompasses the use of plant roots and other plant parts like seedlings and expurgated shoots to adsorb or absorb heavy metals ions and organic contaminants from polluted surface of waters, aqueous environment or wastewaters for cleaning numerous aquatic environments. Once plant roots, excised shoots or seedlings are used during the phytofiltration process to eliminate contaminants from the aqueous environs, it is designated as rhizofiltration, caulofiltration and blastofiltration respectively [13, 64], however rhizofiltration is the most common utilized technique for contaminant elimination.

During the process of rhizofiltration, both aquatic and land-dwelling (terrestrial) plants are used in adsorbing, concentrating and precipitating contaminants from contaminated aqueous bases with low concentration of contaminants from the plant's roots [65]. Though, the use of terrestrial plant in rhizofiltration is more preferable, relative to other plants, because they have a high surface area which is formed by covering of their root hairs with a widespread fibrous root system [13]. More so, it is of great value that the plant used in this technique should be able to adsorb and tolerate reasonable concentrations of heavy metals, stress-free to handle, cost of maintenance should be low, nominal disposal of secondary wastes, high production of root biomass or possession of large surface area of root [66].

For instance, aquatic plants like Potamogeton pectinatus L., Potamogeton natans L and Callitriche stagnalis S. efficaciously reduced concentration of uranium in water bodies from 500.00 to 72.30 g/L [67]. Other aquatic plants that showed some potentialities in decontaminating heavy metal ions include Hydrocotyle umbellata L., Lemna minor L. and Eichhornia crassipes. Though, these plants were reported of having limited rhizofiltration capabilities due to possessing smaller and slower-growing roots [33]. However, terrestrial plants like Indian mustard, sunflower, spinach, rye and corn were investigated for decontaminating Lead (Pb^{2+}) from wastes. Out of the studied plants, Helianthus annus (Sunflower) was the most efficient. Though, the roots of Brassica juncea Czern (Indian mustard) showed higher efficiency in decontaminating Nickel (Ni^{4+}), Copper (Cu^{2+}), Chromium (Cr^{3+}), Zinc (Zn^{2+}) and Cadmium (Cd^{2+}). This technique, Rhizofiltration, could be used to partially decontaminate acid mine drainage, agricultural runoff or industrial discharge. It was equally used to treat polluted sites with copper (Cu^{2+}), Chromium (Cr^{3+}), Zinc (Zn^{2+}), Cadmium (Cd^{2+}), Lead (Pb^{2+}) and Nickel (Ni^{4+}), which are predominantly reserved in their roots [13, 68].

Though, the major advantage of this technique is that it can be carried out either Ex-Situ (outside) or In Situ (inside), and other plant species that are not hyperaccumulators could be used during the process. While the main setback of this technique is that the elevated water content in the aquatic plants enhances the difficulty in drying, composting and incineration [13], after the conduct of the experiment.

4.6 Phytostimulation

Phytostimulation is the technique during which the plants exude out substances at their root zone (rhizosphere) to motivate the fungal or microbial degradation of organic contaminants. The technique works in such a way that the plants supply growth requirements to microorganisms, which help them to augment the degradation of the contaminants [33, 69]. Therefore, it could be seen here that there is an establishment of a mutual or symbiotic association between microorganisms and plants towards achieving such great task of decontamination. The plants release out natural materials and oxygen at their rhizosphere that favor microbial growth, hence the microorganisms accomplish the task of contaminant degradation [46, 70].

5. Generalized Pluses and Minuses of Phyto-Remediation

As it is obtainable in any technology, phytoremediation equally has numerous advantages and disadvantages, which is presented in table 1. When compared to conventional remediation practices, the phytoremediation advantages include: Highly potential in treating or cleaning sites contaminated with many contaminants, economical and cost-efficient technology, reduced risk of spreading contamination because there is no need for the provision of sites for waste disposal, it's pleasant aesthetically when related to traditional technique, and ultimately it's less troublesome to the bionetwork and, at the same time, does not embroils to halt for new plant populations to de-inhabit the polluted site [12, 33, 71].

Notwithstanding, the aforementioned benefits have certain drawbacks; Because it is plant growth- dependent, it's time inefficient when related to other methods, there could be leaching of soluble contaminants that would eventually cause environmental mutilation, it involves the use of agricultural kits and technical know-how to run at industrial scale, it depends on plant growth conditions (like temperature, sunlight, climate, altitude and geology) and therefore accomplishment is influenced by the plants tolerance to the contaminants, high risk of exuding the contaminants gathered in plants senesce tissues being set back to the environment, and finally high concentration of contaminants may be noxious to the plants during the treatment [12, 33], which could ultimately hinder the growth of the plants.

Table 1
The Pluses and Minuses of Phyto-Remediation

Pluses	Minuses
It doesn't necessitate the use of costly equipment or highly expertise to be conducted.	Requires proper disposal of the harvested plant after the treatment, since they are classified as more hazardous than the wild-type plant.
It restricts the spread of contaminants to other the unaffected environments via the process of *In Situ* technique.	The biodiversity may be affected due to the addition of mutant plant species into the environments.
There is a low level of soil disturbances during *In Situ* technique as an analogue to the normal methods of contaminant removal.	It's constrained to environments with lower level of contamination.
It's performed on any environment contaminated by both inorganic and organic composites.	Temperature and other climatic conditions grossly affect the efficiency of the methods.

6. Conclusion

Succinctly, phytoremediation is considered as a cost-effective and an environmentally friendly technique for decontaminating polluted environment. Because the conventional remediation techniques like chemical, thermal, physical and other treatment methods are exorbitant, and may end of causing more contaminations to the environments. Heavy metal ions and other organic substances are among the most precarious substances when established in an environment due to their renowned level of toxicity in the environment. The review eventually concluded that the phytoremediation is an efficient, handy and promising technique that could be utilized effectively in the removal or reduction of environmental contaminations, particularly heavy metal ions.

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References
[1] Thakur, Sveta, Lakhveer Singh, Zularisam Ab Wahid, Muhammad Faisal Siddiqui, Samson Mekbib Atnaw, and Mohd Fadhil Md Din. "Plant-driven removal of heavy metals from soil: uptake, translocation, tolerance mechanism, challenges, and future perspectives." *Environmental monitoring and assessment* 188, no. 4 (2016): 206.

[2] Alkorta, I., J. Hernández-Allica, J. M. Becerril, I. Amezaga, I. Albizu, and C. Garbisu. "Recent findings on the phytoremediation of soils contaminated with environmentally toxic heavy metals and metalloids such as zinc, cadmium, lead, and arsenic." *Reviews in Environmental Science and Biotechnology* 3, no. 1 (2004): 71-90.

[3] Chaney, Rufus L., Minnie Malik, Yin M. Li, Sally L. Brown, Eric P. Brewer, J. Scott Angle, and Alan JM Baker. "Phytoremediation of soil metals." *Current opinion in Biotechnology* 8, no. 3 (1997): 279-284.

[4] Cui, Yanshan, Qingren Wang, Yiting Dong, Haifeng Li, and Peter Christie. "Enhanced uptake of soil Pb and Zn by Indian mustard and winter wheat following combined soil application of elemental sulphur and EDTA." *Plant and Soil* 261, no. 1 (2004): 181-188.

[5] Alkorta, I., J. Hernández-Allica, J. M. Becerril, I. Amezaga, I. Albizu, M. Onaindia, and C. Garbisu. "Chelate-enhanced phytoremediation of soils polluted with heavy metals." *Reviews in Environmental Science and Biotechnology* 3, no. 1 (2004): 55-70.

[6] Edward, Hingha F. J., Nurul As'shikin R., Hairu Nabilah I., Nulhazwany A., Hazlami Fikri B., Fatihah Syahirah A. and Nurul Sakinah M. N., Fairoz J. "Municipal solid waste characteristics in Taman Universiti, Skudai, Johore, Malaysia." *Journal of Advanced Research Design* 38, 1 (2017) 13-20

[7] Ab Jalil, N., Basri, H., Basri, N. A., and Abushammala, M. F. "The Potential of Biodrying as Pre-treatment for Municipal Solid Waste in Malaysia." *Journal of Advanced Review on Scientific Research* 7, no. 7 (2015): 1-13.

[8] Newton, M., Sulaiman, M., Saidu, H., Galadima, A. I., Umar, D. M., Kotos Abubakar, M. K., and Billah, C.. "Akademia Baru." *Journal of Advanced Research Design* 36, no. 1 (2017): 13-24.

[9] Liu, Xingmei, Qiujin Song, Yu Tang, Wanlu Li, Jianming Xu, Jianjun Wu, Fan Wang, and Philip Charles Brookes. "Human health risk assessment of heavy metals in soil–vegetable system: a multi-medium analysis." *Science of the Total Environment* 463 (2013): 530-540.

[10] Beiergrohslein, Erik Hans. "Use of Surfactants in Removal of Zinc, Lead and Cadmium from Contaminated Soils." PhD diss., Oklahoma State University, 1998.

[11] Jonnalagadda, S. B., and PVV Prasada Rao. "Toxicity, bioavailability and metal speciation." *Comparative Biochemistry and Physiology Part C: Pharmacology, Toxicology and Endocrinology* 106, no. 3 (1993): 585-595.

[12] Gardea-Torresdey, Jorge L., Jose R. Peralta-Videa, G. De La Rosa, and J. G. Parsons. "Phytoremediation of heavy metals and study of the metal coordination by X-ray absorption spectroscopy." *Coordination chemistry reviews* 249, no. 17 (2005): 1797-1810.

[13] Ghosh, M., and S. Singh. "A review on phytoremediation of heavy metals and utilization of it's by products." *Asian J Energy Environ* 6, no. 4 (2005): 18.

[14] Stegmann, Rainer, Gerd Brunner, Wolfgang Calmano, and Gerhard Matz, eds. *Treatment of contaminated soil: fundamentals, analysis, applications*. Springer Science & Business Media, 2013.

[15] Mulligan, C. N., R. N. Yong, and B. F. Gibbs. "Remediation technologies for metal-contaminated soils and groundwater: an evaluation." *Engineering geology* 60, no. 1 (2001): 193-207.

[16] Leopold, Kerstin, Michael Foulkes, and Paul Worsfold. "Methods for the determination and speciation of mercury in natural waters—a review." *Analytica chimica acta* 663, no. 2 (2010): 127-138.

[17] Li, Chunjie, Yang Dong, Deyi Wu, Licheng Peng, and Hainan Kong. "Surfactant modified zeolite as adsorbent for removal of humic acid from water." *Applied clay science* 52, no. 4 (2011): 353-357.

[18] Blowes, David W., Carol J. Ptacek, Shawn G. Benner, Che WT McRae, Timothy A. Bennett, and Robert W. Puls. "Treatment of inorganic contaminants using permeable reactive barriers." *Journal of Contaminant Hydrology* 45, no. 1 (2000): 123-137.

[19] Lehmann, M., A. I. Zouboulis, and K. A. Matis. "Modelling the sorption of metals from aqueous solutions on goethite fixed-beds." *Environmental pollution* 113, no. 2 (2001): 121-128.

[20] Evangelou, Michael WH, Mathias Ebel, and Andreas Schaeffer. "Chelate assisted phytoextraction of heavy metals from soil. Effect, mechanism, toxicity, and fate of chelating agents." *Chemosphere* 68, no. 6 (2007): 989-1003.

[21] Reddy, Krishna R., and Supraja Chinthamreddy. "Sequentially enhanced electrokinetic remediation of heavy metals in low buffering clayey soils." *Journal of Geotechnical and Geoenvironmental Engineering* 129, no. 3 (2003): 263-277.

[22] Zhou, Dong-Mei, Chang-Fen Deng, and Long Cang. "Electrokinetic remediation of a Cu contaminated red soil by conditioning catholyte pH with different enhancing chemical reagents." *Chemosphere* 56, no. 3 (2004): 265-273.

[23] Fingerman, Milton, ed. *Bioremediation of aquatic and terrestrial ecosystems*. CRC Press, 2016.

[24] Samanta, Sudip K., Om V. Singh, and Rakesh K. Jain. "Polycyclic aromatic hydrocarbons: environmental pollution and bioremediation." *TRENDS in Biotechnology* 20, no. 6 (2002): 243-248.

[25] Watanabe, Kazuya. "Microorganisms relevant to bioremediation." *Current opinion in biotechnology* 12, no. 3 (2001): 237-241.

[26] Francis, A. J. "Biotechnology of radioactive wastes: a general overview." In *Biotechnology for Waste Management and Site Restoration*, pp. 19-28. Springer, Dordrecht, 1997.

[27] Park, Donghee, Yeoung-Sang Yun, and Jong Moon Park. "The past, present, and future trends of biosorption." *Biotechnology and Bioprocess Engineering* 15, no. 1 (2010): 86-102.

[28] Peng, Kejian, Chunling Luo, Laiqing Lou, Xiangdong Li, and Zhenguo Shen. "Bioaccumulation of heavy metals by the aquatic plants Potamogeton pectinatus L. and Potamogeton malaianus Miq. and their potential use for contamination indicators and in wastewater treatment." *Science of the total environment* 392, no. 1 (2008): 22-29.
[29] Mathew, Ann Mary. "Phytoremediation of heavy metal contaminated soil." PhD diss., Oklahoma State University, 2005.
[30] Pilon-Smits, Elizabeth. "Phytoremediation." *Annu. Rev. Plant Biol.* 56 (2005): 15-39.
[31] Bhargava, Atul, Francisco F. Carmona, Meenakshi Bhargava, and Shilpi Srivastava. "Approaches for enhanced phytoextraction of heavy metals." *Journal of Environmental Management* 105 (2012): 103-120.
[32] Tangahu, Bieby Voijant, Siti Rozaimah Sheikh Abdullah, Hassan Basri, Mushrifah Idris, Nurina Anuar, and Muhammad Mukhlisin. "A Review on heavy metals (As, Pb, and Hg) uptake by plants through phytoremediation." *International Journal of Chemical Engineering* 2011 (2011).
[33] Akpor, O. B., and M. Muchie. "Remediation of heavy metals in drinking water and wastewater treatment systems: Processes and applications." *International Journal of Physical Sciences*5, no. 12 (2010): 1807-1817.
[34] Ali, Hazrat, Ezzat Khan, and Muhammad Anwar Sajad. "Phytoremediation of heavy metals—concepts and applications." *Chemosphere* 91, no. 7 (2013): 869-881.
[35] Gaur, Nisha, Gagan Flora, Mahavir Yadav, and Archana Tiwari. "A review with recent advancements on bioremediation-based abolition of heavy metals." *Environmental Science: Processes & Impacts* 16, no. 2 (2014): 180-193.
[36] Dushenkov, Viatcheslav, PBA Nanda Kumar, Harry Motto, and Ilya Raskin. "Rhizofiltration: the use of plants to remove heavy metals from aqueous streams." *Environmental science & technology* 29, no. 5 (1995): 1239-1245.
[37] Parmar, Shobhika, and Vir Singh. "Phytoremediation approaches for heavy metal pollution: a review." *J Plant Sci Res* 2, no. 2 (2015): 135.
[38] Purakayastha, T. J., and P. K. Chhonkar. "Phytoremediation of heavy metal contaminated soils." In *Soil heavy metals*, pp. 389-429. Springer Berlin Heidelberg, 2010.
[39] Schat, H., M. Llugany, R. Bernhard, N. Terry, and G. Banuelos. "Metal-specific pattern of tolerance, uptake, and transport of heavy metals in hyperaccumulating and non-hyperaccumulating metallophytes." *Phytoremediation of Contaminated Soils and Water.* (2000): 171-188.
[40] Thangavel, P., and C. V. Subbhuraam. "Phytoextraction: role of hyperaccumulators in metal contaminated soils." *Proceedings-Indian National Science Academy Part B* 70, no. 1 (2004): 109-130.
[41] Zhao, F. J., E. Lombi, and S. P. McGrath. "Assessing the potential for zinc and cadmium phytoremediation with the hyperaccumulator Thlaspi caerulescens." *Plant and soil* 249, no. 1 (2003): 37-43.
[42] Solhi, Mahmoud, Hossain Shareatmadari, and Mohammad A. Hajabbasi. "Lead and zinc extraction potential of two common crop plants, Helianthus annuus and Brassica napus." *Water, Air, & Soil Pollution* 167, no. 1 (2005): 59-71.
[43] Fodor, L., & Szabó, L. (2006). Chemical detection of heavy metals applied at high rates to soil. *Communications in soil science and plant analysis*, *37*(15-20), 2523-2530.
[44] Rosariastuti, Retno, Irfan Dwidya Prijambada, N. Ngadiman, Gani Sisca Prawidyarini, and Angry Rosha Putri. "Isolation and identification of plant growth promoting and chromium uptake enhancing bacteria from soil contaminated by leather tanning industrial waste." *Journal of Basic & Applied Sciences*9 (2013): 243.
[45] Nowack, Bernd, Rainer Schulin, and Brett H. Robinson. "Critical assessment of chelant-enhanced metal phytoextraction." *Environmental Science & Technology* 40, no. 17 (2006): 5225-5232..
[46] Lasat, Mitch M. "Phytoextraction of toxic metals." *Journal of environmental quality* 31, no. 1 (2002): 109-120.
[47] Cobbett, Christopher S. "Phytochelatins and their roles in heavy metal detoxification." *Plant physiology* 123, no. 3 (2000): 825-832..
[48] Kushwaha, Anamika, Radha Rani, Sanjay Kumar, and Aishvarya Gautam. "Heavy metal detoxification and tolerance mechanisms in plants: implications for phytoremediation." *Environmental Reviews* 24, no. 1 (2015): 39-51.
[49] Henry, Jeanna R. *An overview of the phytoremediation of lead and mercury*. Washington, DC: US Environmental Protection Agency, Office of Solid Waste and Emergency Response, Technology Innovation Office, 2000.
[50] Yao, Zhitong, Jinhui Li, Henghua Xie, and Conghai Yu. "Review on remediation technologies of soil contaminated by heavy metals." *Procedia Environmental Sciences* 16 (2012): 722-729.
[51] Bizily, Scott P., Clayton L. Rugh, and Richard B. Meagher. "Phytodetoxification of hazardous organomercurials by genetically engineered plants." *Nature biotechnology* 18, no. 2 (2000): 213-217.
[52] Lucy, M., E. Reed, and Bernard R. Glick. "Applications of free living plant growth-promoting rhizobacteria." *Antonie van leeuwenhoek* 86, no. 1 (2004): 1-25.

[53] Jin, Xu, and Shaohong You. "Soil pollution of abandoned tailings in one zinc antimony mine and heavy metal accumulation characteristics of dominant plants." In *International Conference on Materials, Environmental and Biological Engineering, Guilin*, pp. 500-504. 2015.
[54] Tordoff, G. M., A. J. M. Baker, and A. J. Willis. "Current approaches to the revegetation and reclamation of metalliferous mine wastes." *Chemosphere* 41, no. 1 (2000): 219-228.
[55] Sharma, Sunita, Bikram Singh, and V. K. Manchanda. "Phytoremediation: role of terrestrial plants and aquatic macrophytes in the remediation of radionuclides and heavy metal contaminated soil and water." *Environmental Science and Pollution Research* 22, no. 2 (2015): 946-962..
[56] Mendez, Monica O., and Raina M. Maier. "Phytostabilization of mine tailings in arid and semiarid environments—an emerging remediation technology." *Environmental health perspectives* 116, no. 3 (2008): 278.
[57] Yoon, Joonki, Xinde Cao, Qixing Zhou, and Lena Q. Ma. "Accumulation of Pb, Cu, and Zn in native plants growing on a contaminated Florida site." *Science of the total environment*368, no. 2 (2006): 456-464.
[58] Rizzi, L., G. Petruzzelli, G. Poggio, and G. Vigna Guidi. "Soil physical changes and plant availability of Zn and Pb in a treatability test of phytostabilization." *Chemosphere* 57, no. 9 (2004): 1039-1046.
[59] Singh, Munendra, German Müller, and I. B. Singh. "Heavy metals in freshly deposited stream sediments of rivers associated with urbanisation of the Ganga Plain, India." *Water, Air, & Soil Pollution* 141, no. 1 (2002): 35-54.
[60] Ander, E. Louise, Christopher C. Johnson, Mark R. Cave, Barbara Palumbo-Roe, C. Paul Nathanail, and R. Murray Lark. "Methodology for the determination of normal background concentrations of contaminants in English soil." *Science of the Total Environment* 454 (2013): 604-618.
[61] Caçador, Isabel, and Bernardo Duarte. "Chromium phyto-transformation in salt marshes: the role of halophytes." In *Phytoremediation*, pp. 211-217. Springer International Publishing, 2015.
[62] Sayer, Jacqueline A., and Geoffrey M. Gadd. "Solubilization and transformation of insoluble inorganic metal compounds to insoluble metal oxalates by Aspergillus niger." *Mycological Research* 101, no. 6 (1997): 653-661.
[63] Blake, Robert C., Donna M. Choate, Smriti Bardhan, Nathaniel Revis, Larry L. Barton, and Thomas G. Zocco. "Chemical transformation of toxic metals by a Pseudomonas strain from a toxic waste site." *Environmental Toxicology and Chemistry*12, no. 8 (1993): 1365-1376.
[64] Morais, I., J. S. Campos, P. J. C. Favas, J. Pratas, F. Pita, and M. N. V. Prasad. "Nickel accumulation by Alyssum serpyllifolium subsp. lusitanicum (Brassicaceae) from serpentine soils of Bragança and Morais (Portugal) ultramafic massifs: plant–soil relationships and prospects for phytomining." *Australian Journal of Botany* 63, no. 2 (2015): 17-30.
[65] Zhuang, Ping, Q. W. Yang, H. B. Wang, and W. S. Shu. "Phytoextraction of heavy metals by eight plant species in the field." *Water, Air, and Soil Pollution* 184, no. 1-4 (2007): 235-242.
[66] Padmavathiamma, Prabha K., and Loretta Y. Li. "Phytoremediation technology: hyper-accumulation metals in plants." *Water, Air, and Soil Pollution* 184, no. 1-4 (2007): 105-126.
[67] Sasmaz, Merve, Erdal Obek, and Ahmet Sasmaz. "Bioaccumulation of uranium and thorium by Lemna minor and Lemna gibba in Pb-Zn-Ag tailing water." *Bulletin of environmental contamination and toxicology* 97, no. 6 (2016): 832-837.
[68] Zabihi, M., A. Haghighi Asl, and A. H. M. A. D. Ahmadpour. "Studies on adsorption of mercury from aqueous solution on activated carbons prepared from walnut shell." *Journal of hazardous materials* 174, no. 1 (2010): 251-256.
[69] Liyuan, Niu. "Phytoremediation of heavy metal contaminated soils." *Journal of Henan Institute of Science and Technology (Natural Science Edition)* 2 (2010): 014.
[70] Meers, Erik, and Filip Tack. "The potential of foliar treatments for enhanced phytoextraction of heavy metals from contaminated soil." *Remediation Journal* 14, no. 4 (2004): 111-123.
[71] Raskin, Ilya, and Burt D. Ensley. *Phytoremediation of toxic metals*. John Wiley and Sons, 2000.