Review

Phytoremediation: green technology for improving aquatic and terrestrial environments

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Abstract. Environmental remediation by traditional physicochemical methods has several drawbacks, the most important of which is the high cost. Phytoremediation is the use of plants and associated microorganisms to improve degraded environments. Plant sensitivity to climate, seasonal growing, resistant to toxic compounds and suspended solids are limitations of this cost effective technology. Costs of phytoremediation can be offset by the production of valuable biomass for timber, fuel, essential oils and other uses. In some cases, the biomass may contain high concentrations of valuable trace elements such as nickel. Successful phytoremediation depends on suitable plants selection and application of appropriate agronomic techniques. In most cases, locally native plants are the most suitable phytoremediator for phytoremediation. This review collected 20 phytoremediation related terms containing phytomining, agromining, phytoextraction, phytostabilization, rhizoremediation, phytodegradation, rhizodegradation, phytovolatilization, phytopumping, phytotransformation, phytofiltration, rhizofiltration, phytoremediation, dendroremediation, cyanoremediation, mycoremediation, phytosequestration, phytoimmobilization, phytoaccumulation, phytostimulation, and phytodesalination. More than 200 research article reviewed for this paper.

Keywords: Biodegradable, Mechanism, hyperaccumulator, Sustainable protection of environment

1. INTRODUCTION

Environmental degradation may arise through both natural and anthropogenic processes (Tarzia et al., 2002). Overpopulation and waste management are two sides of industrialization (Farraji et al., 2016) which is clear indicator for necessity of environmental improvement.

Physicochemical technologies for the decontamination of polluted sites include chemical precipitation, membrane filtration, adsorption, coagulation-flocculation, Photocatalytic degradation, ion exchange, oxidation with ozone, oxidation with hydrogen peroxide, flotation and electrochemical methods (Fu and Wang, 2011) are high cost and cannot be used as a single process to achieve environmental standards (Ahmaruzzaman, 2011). Cost effective, eco-friendly green technology is urgently required for improving degraded environments. These remediation methods should be fundamentally sustainable treatment technologies for gaining suitable environmentally sound goals.

Phytoremediation is the use of plants to improve degraded environments (Robinson et al., 2003). Phytoremediation can be divided into specific mechanisms, including phytostabilization, phytoextraction, phytovolatilization, phytoremediation, phytodegradation, phytodesalination, rhizofiltration and rhizodegradation (Awa and Hadibarata, 2020). These subsets are divided based on the goal of phytoremediation, the media in which phytoremediation occurs and the types of contaminants that are present. Phytoremediation is invariably a slow treatment method compared to other (Weatherford et al., 1997) which was presented in the early years of phytoremediation technology appearance stated that only 75 polluted sites from all 1300 national contaminated sites in US were decontaminated through the 15 years. Nowadays, numerous of advanced techniques added as new subsets for this green technology and additional augmentation and amendment are suitably applied for high-efficiency environmental cleaning even with 100 % pollutant removal in a short time (Gangola et al., 2015).

Plant selection is a critical success factor for phytoremediation. High biomass plant species with high tolerance to elevated concentrations of several contaminants are often desirable characteristics. The most suitable plant species may often be found colonizing polluted areas (Farraji, 2014; Farraji et al., 2016; Robinson et al., 1999), such as plants growing in abandoned mine sites. Species such as *Phyllanthus balgooyi*, which is a Nickel hyperaccumulator (Van der Ent et al., 2013b) and *Phytolacca acinosa* Roxb growing in manganese tailings (Xue et al., 2004). Alternatively, native vegetation or even crop plants may be established on contaminated sites, potentially with the judicious use of soil conditioners.

Suitable plant selection for phytoremediation extremely depends on the nature of the contaminants and their concentrations (Pilon-Smits, 2005), age of the site (Hutchinson et al., 2001), depth (Cunningham et al., 1996) volatilization rate (Ghosh & Singh, 2005) and biodegradability (Joner & Leyval, 2003). Furthermore, the selection of a suitable green technology for specific pollution is essential for effective phytoremediation. For example, inorganic pollution could be treated by phytostabilization, phytovolatilization and rhizoremediation methods (Cunningham et al., 1996; Nwoko, 2013) based on their physicochemical characteristics and concentration as well as their biodegradability.

Phytoremediation process can be enhanced through soil conditioners, such as compost (Mangkoedihardjo, et al., 2008), cow dung (Essien et al., 2015; Njoku et al., 2012), olive waste (Nogales and Benítez, 2006), rhizobacteria (Gurska et al., 2009; Langella et al., 2014), biochar (Houben et al., 2013), adsorbent (Mojiri et al., 2016), and plant growth promoters (Vamerali, 2011). The main target of this review is to present different merit aspects of phytoremediation as green technology and their eligibility for environmental cleaning.

2. PHYTOREMEDIATION: TYPES AND RELATED DEFINITION

There are several types of phytoremediation methods, mechanisms, techniques, and related definitions which frequently cited in literatures. Alkorta and Garbisu, (2001) divided phytoremediation to 2 main types. Cluis, (2004) classified 4 types of phytoremediation for soil decontamination. Vishnoi and Srivastava, (2007) explained 6 types of phytoremediation. Bora and Sarma, (2020) explained 7 types of phytoremediation based on the types of plant, condition of site, and characteristics of contaminants. In this review the main types of phytoremediation techniques, mechanisms of phytoremediation, equal definition for a specific remediation in literatures, bacteria, algae, and fungi based phytoremediation as well as traditional definition for phytoremediation explained.

2.1. Rhizoremediation

Plants release sugar, amino acids and alcohols into the rhizosphere, which form a substrate for the growth of bacteria and fungi (Mishra and Arora, 2019). These microorganisms can be selected to degrade specific soil contaminants. Several amendments and augmentation techniques can enhance the efficiency of this treatment method, including enzymes (Chen et al., 2016) organic matter (Baudoin et al., 2003), plant growth promoters (Ganesan, 2008) and biosurfactants (Khatishashvili et al., 2015) have been used. Rhizoremediation can treat a wide range of pollutants including the immobilization of metallic elements (Chien et al., 2015; Wang et al., 2013), PAHs (Bisht et al., 2014; Feng et al., 2014), Polychlorinated biphenyl (Pino et al., 2016), petroleum (Akhundova and Atakishiyeva, 2015; Mohsenzadeh et al., 2010), herbicide (Zhu et al., 2012). This type of phytoremediation is going to be a major part of phytoremediation and nowadays have high concerning by scientists and research groups for both biodegradable and non-biodegradable pollutants. Rhizoremediation could be an advanced compact combination of phytoextraction, phytovolatilization, phytotransformation and phytostabilization (Farraji et al., 2017).

2.2. Rhizodegradation

This phytotreatment method is also known as phytostimulation (Souza et al., 2013). Rhizodegradation normally applies for terrestrial media and defined as bioremediation / degradation of organic contaminants (hydrocarbons) in the rhizosphere area with the assistance of microbial communities. Plant-microbial interaction plays a critical role in the efficiency of this treatment method. Microorganisms in the plant rhizosphere can break down hazardous organic contaminants, such as herbicides (Lin et al., 2011), perchlorate (Yifru and Nzungu, 2008), crude oil (Unterbrunner et al., 2007), Polyhydroxy aromatic compounds (Lu et al., 2011), and diesel (Kaimi et al., 2007) to harmless and /or nontoxic products. Sugar, amino acid and alcohols are released by plant roots and microbial communities use these energy and food sources for consuming and digesting organic pollutants. This method is a highly rapid treatment system in comparing with phytodegradation because of microbial community association. The biostimulation of microbial activities in the rhizosphere of phytoremediator plant species can accelerate the degradation of several xenobiotic compounds (Arshad et al., 2007).

2.3. Phytovolatilization

Phytovolatilization which is also known as phytopumping highly depends on physical properties of pollutants. The, polarity, solubility and hydrophobicity should be contained in target pollutants. Readily soluble in water and volatile organic compound could be treated by this type of phytoremediation technique. Phytovolatilization can be used for heavy metals (As, Se and Hg), BTEX, MTBE, TCE, vinyl chloride, carbon tetrachloride, 1,4-dioxane (Dhillon et al., 2010; Edwards et al., 2011; Heaton et al., 1998; Sakakibara et al., 2010). Limitation and drawbacks of phytovolatilization can be summarized thus:

- The pollutants should be soluble to uptake by plant roots
- Transferring to leaves should be done properly
- Converting to volatile form in the plant tissues
- Volatilize to atmosphere in final process

1. Hyperaccumulator or genetically modified plants have the greatest potential for phytovolatilisation (Meagher and Heaton, 2005). Following tips are essential for phytovolatilisation (Chen et al., 2017, Di et al., 2019,).

2. Plant tolerance to high concentration of toxic pollutants
3. Ability of plant for altering their rhizosphere for higher uptake essential and toxic elements
4. Availability of endogenous transporters in hairy roots
5. Electrochemical capability of elemental pollutants for increasing upward mobility in plant
6. Strong xylem for transporting essential nutrients from roots to leaves
7. Capability of aboveground parts of plant in electrochemical and chemical controlling pollutants
8. Suitable chemical sink to enhancing essential elements (Fe, Zn, Cu, sulfate and phosphate) storage
9. Suitable physical sink to limited pollutants in high concentration in aboveground tissues

Heavy metals are non-degradable pollutants and phytoremediation techniques for these hazardous materials are limited to phytoextraction and phytomining. Heavy metal phytovolatilization may be investigated for As, Hg, and Se which can exist as gases in the natural environment. The toxic nature of gaseous Hg and Se is a serious drawback when considering phytovolatilisation.

2.3.1. Arsenic

The first report of arsenic hyperaccumulator plant species, *Pteris vittata* (Ma et al., 2001) opened new opportunities to remove this toxic element from soil. All As hyperaccumulators reported to date are ferns, except for *Pityrogramma calomelanos*, ferns (*Pteris*) (Chakrabarty, 2015). After extracting arsenic from contaminated soil and accumulating it in stems and frond, toxic element laden biomass is another environmental problem. Thus, finding plant with ability to absorb this metals from soil, degraded to gaseous species by biological converting and finally releasing this gaseous metallic elements to atmosphere is the major foundation of phytovolatilization of arsenic. Nevertheless, finding suitable plants for these issues are quite hard and transgenic plants could increase or add ligands to make hosted plants eligible for phytovolatilization. *Pteris vittata* is a capable arsenic hyperaccumulator since of following specification:

1. Extremely high tolerance to arsenic >1% dry weight
2. Remarkable biomass production, especially root exudates
3. High translocation index
4. High ability in reduction As (V) to As (III)
5. Capability to keep phosphorus in high concentration (Ma et al., 2001)
6. Capability to releasing arsenic from secretory glands of the fronds (Hokura et al., 2006)
7. As detoxification is consequence of enzymatic and non-enzymatic antioxidants (Cao et al., 2004)
8. Gametophytes of *p. vittata* can grow in high concentration of arsenic (Gumaelius et al., 2004)
9. Ability to volatilization of 90% arsenic uptake (Sakakibara et al., 2010)
10. Eligible for enhancing As volatilization by organic amendment (Dhillon et al., 2010)

2.3.2. Mercury

This element has the ability to form very strong covalent bonds with sulfur groups in terrestrial media consequently mobility of mercury from laden (contaminated or natural) land and sediments (Krabbenhoft and Babiarez, 1992; Wallschläger et al., 1996). Humic substances also could be the target of forming strong bonds by mercury elements and finally stabilizing Hg^{2+} in the atmosphere. Aquatic media are suitable for Hg^{2+} reduction to $Hg(0)$. Genetically modified *Arabidopsis thaliana* and *Nicotiana tabacum* contain can reduce Hg by gene than convert $Hg(II)$ to $Hg(0)$,

which is the less toxic metallic mercury and it can easily volatilize to the atmosphere (Meagher, 2000). Plants which engineered by modified bacterial mercuric reductase gene, *merA*, could be considered as suitable to remove available inorganic mercury and methylmercury from contaminated terrestrial and sediments. *Arabidopsis thaliana* and *Nicotiana tabacum* are two traditional plant species which capable for the genetic engineering process (Heaton et al., 1998). *Liriodendron tulipifera* tissue was cultured and assisted by *merA* gene to construct the reduction of toxic ionic mercury, Hg (II) to elemental mercury, Hg (0). Gen transformed plantlet germinate and grew well in mercury-contaminated land and these plantlets could release mercury 10 times more than the control (untransformed) (Rugh et al., 1998). Mercury removal from aquatic media also could be planned by combining phytoremediation methods, such as phytofiltration and phytovolatilization to reach higher efficiency in pollutant removal. Moreno et al. (2008) method causes 95% removal by *Brassica juncea* L.

2.3.3. Selenium

Phytovolatilization is a term for the volatilization of Se, Hg and As with plant species. Phytoremediation first coined by Raskin in 1994 and related “phyto” techniques used based on the main mechanism of removal. Furthermore, based on the our best computer navigation science, the first article which used phytovolatilization belongs to Terry et al. (1995). Nevertheless, the historical background of selenium volatilization by plants belongs to Lewis et al. (1966), which used *Astragalus racemosus* as accumulator plant species and *Medicago sativa* as non-accumulator plant species. The final report of that study indicates that; plant foliage is the main volatilization part and the rate of Se volatilization has a high correlation with daytime. Comparing accumulator and non-accumulator plant for selenium volatilization were recently investigated by Statwick et al. (2016). Volatilization of selenium is highly depended on soil microbial communities. Based on the report of Chau et al. (1976) and Reamer and Zoller (1980), sterilization of soil by steam causes elimination of microbial activities, consequently, Se volatilization totally will be stopped. Higher recorded volume of volatilization of Se was during spring compared with the same period in winter, which is reported by McDonald & Duncan. (1979) is another confirmation for microbial basement of volatilization, which normally is very high in spring and extremely decrease in winter. Furthermore, volume of volatilized Se have linear correlation with volume of water-soluble selenium in soil (Abu et al., 1968; Zieve & Peterson, 1981). *Agrostis tenuis* showed linear correlation in volatilization of selenium with time as variable factor. The presence and concentration of Se in soil are major factors in volume and the mechanism of volatilization. In high concentration or the rise of Se, accumulation of this element will carry out in the root by ion exchange mechanism. Meanwhile, low concentration or increasing rate of selenium known as uptake.

2.4. Phytotransformation

This phytotreatment method is also known as phytodegradation. In this environmental cleaning method which is only applicable for degradable pollutants, pollutants uptake by plant and their breaking down process to nonhazardous material carried out in plant body through the metabolic process. Organic compounds such as petroleum (De-Farias et al., 2009; Park et al., 2011) by *Helianthus annuus*, *Brassica campestris*, *Festuca arundinacea*, pesticide (Schwitzguébel et al., 2006), dye (Kagalkar et al., 2011) by *Blumeam alcolmii*, TNT (Das et al., 2012) by *Chrysopogon zizanioides* had been treated by phytodegradation. This green technology which is based on herbal phytoremediator plant species highly suffers from long treatment time. This causes an increase in environmental risk of pollutants among the long period of decontamination time.

This technique is also based on the plant (hairy roots) ability of degradation or transformation of pollutants inside or outside of plant tissues by the compounds which normally produce by plants such as enzymes. In case of outside transformation of pollutants, the required compounds for degradation are released from plant roots. The target pollutants for this treatment method should be degradable and, usually, organic compounds are set as an objective of decontamination. Previous researchers illustrate that this technique enrolled enzymes through the phytotransformation are the peroxidase, cytochromes, and laccases, which followed by their conjugation with glutathione, glucose or peptides in vacuole and /or cell wall apoplast. Primary studies concentrated on aquatic plant species (Adler et al., 1994). Meanwhile, in vitro cell, tissue culture (Suresh et al., 2005) was used in recent research. Transgenic plant for enhancing degradation efficiency (Alderete et al., 2009), hairy roots as metabolizer of toxic compounds pathway common metabolic system in aquatic media and the presence of H₂O₂ for xenobiotic stress protection (Singh et al., 2006) are used through the phytotransformation research process. Most of related studies to phytodegradation concentrate on phenol removal. Nevertheless, wide range of pollutants has been demonstrated by previous investigation on PCB (Rezek et al., 2008), TNT (Hughes et al., 1996) and DDT by phytodegradation technique.

Phytodegradation had been improved from lab scale studies for the past decades and pilot studies (Alderete et al., 2012) for phenol removal are going to improve it as an eligible commercial treatment method in the future. In many

cases, detoxification of pollutants is controlled by oxidoreductive enzymes (peroxidases), which are exuded in high volume by plants in response to water pollutants, and environmental chemical stress. These abundant isoenzymes mainly localized in vacuoles and cell walls (Coniglio et al., 2008). Plant species with the ability to produce hairy roots and suitable enzyme plays a main role in degradation of pollutants and several species have been investigated in literatures (Table 1). Furthermore, new plants such as garlic (Wang et al., 2015) and belladonna (Mazaheri and Piri, 2015) are cases of most recent studies. In a nutshell, focusing on optimization metabolisms and pollutants is one side of the future improvements in phytodegradation technique and the enhancement of pollutants uptake and degradation capacity is the other side of this precious green technology (Agostini et al., 2013).

2.5. Phytofiltration

In aquatic media as major and critical part of polluted environment, phytoremediation is known as the term of phytofiltration (rhizofiltration), which is an advanced plant base remediation for soluble pollutants. In other words, plants application for contaminant removal from aquatic media (water and aqueous waste streams). This attractive technique could be classified as following tips:

1. Rhizofiltration in hydroponically growing plant roots
2. Bioadsorbent based methods
3. Lagoons and constructed wetlands

As a non-conventional types of phytoremediation for wastewater treatment, phytofiltration is a capable aquatic treatment. Multiple related advantages of this environmentally sound treatment alternative caused it to gain interest nowadays (Olguín, 2003; Olguín and Sánchez, 2010). Aquatic plant species (floating, emergent or submerged) with their hairy roots (in most cases) or fronds (only aquatic ferns) do the removal process. This technique could be challenged in are such as, air waste (CO₂), aquatic media nutrients and xenobiotic of wastewater. The main involved parts through the treatment process are roots, stems, leaves (fronds), water column and microbial communities biomass (Olguín & Sánchez, 2012). There are some challenges on removal efficiency by phytofiltration method, especially in the case of heavy metal adsorption in a natural environment. Lu et al. (2011) selected two ponds with total area 7500 m² and covered 1/20 total area with water lettuce. They collected 135 samples and analyzed Cr, Mn, Co, Pb, Cd, Fe, Zn, Al, Ni, Cu, K, Ca, Mg and Na. Their results indicate that pollutant removal in natural environment is far different with the laboratory researches in controlled conditions. Anyway, in comparing with traditional treatment such as adsorption, photocatalytic degradation, chemical precipitation, coagulation-flocculation hydrogen peroxide and ozone oxidation or electrochemical methods (Kurniawan et al., 2006), which are not only high cost and faced on with disposal problem, but also could not achieve the desired or acceptable results as water quality, Phytofiltration, even with low efficiency in natural condition, is a cost effective environmentally sound green method for waste management. In case of toxic metal (currently known as metallic elements), it is a suitable treatment method. Aquatic phytoremediation as an eco-friendly plant base treatment is the same as Mother Nature; sustainable, trustable and without switching a problem to another environmental problem (Farraji, 2018). Biosorbent-base system, natural/constructed wetlands, rhizofiltration systems, lagoons, hydroponic plant base treatment could be classified as phytofiltration (Olguín and Sánchez, 2010; Sánchez and Olguín, 2009), which often are short time treatment methods. Figure 1 illustrates classification of phytofiltration systems with aquatic plants. And Table 1 shows numerous of recent phytofiltration studies.

Figure 1. Classification of phytofiltration systems (Olguín and Sánchez, 2010)

Table 1. Phytofiltration of pollutants as short time phytoremediation technology

Plant/s	Pollution/s	Time	Untreated concentration	Removal %	Reference
<i>Helianthus annuus</i> L.	U Ra	2 days	2.5×10^{-4} g U 1.1×10^{-10} g	50% 70 %	(Tomé et al., 2008)
<i>Limnocharis flava</i> L.	Cd	3-30 day	0.5-4mg/L	93% in low level	(Abhilash et al., 2009)
<i>Brassica juncea</i> L.	Hg	5 day	0-10 mg/L	95%	(Moreno et al., 2008)
<i>Spirodela polyrrhiza</i>	As	72 h	190ng/mL	41	(Zhang et al., 2011)
<i>Pistia stratiotes</i>	Heavy metals	60 days	44 -0.0053 mg/L	20	(Lu et al., 2011)
<i>Carex pendula</i>	Pb	2 week	0-10 mg/L	1600mg/kg	(Yadav et al., 2011)
<i>Hydrilla verticillata</i>	As	45 days	1500 µg/L	72% in field	(Srivastava, 2011)
<i>Pistia stratiotes</i> L. <i>Salvinia auriculata</i> <i>Salvinia minima</i> <i>Azolla filiculoides</i>	Cd Pb	2 week 2 week	3.5-10.5mg/L 25-125 mg/L	624-3923 mg/kg 3867-42862 mg/kg	(Vesely et al., 2011)
<i>Micranthemum umbrosum</i>	As Cd	7 days	As:1.0 µg/L Cd:30.0 µg/L	AS: 89.5% Cd: 73.1%	(Islam et al., 2013)
<i>Micranthemum umbrosum</i>	As Cd	7 days	As:500 µg /L Cd:500 µg /L	Uptake pattern: leaf>stem>root	(Islam et al., 2015)
<i>Ranunculus trichophyllus</i> <i>Typha latifolia</i> <i>Lemna minor</i> , <i>Spirodela polyrrhiza</i> , <i>Myriophyllum spicatum</i>	Pb, Cu, Zn	Not given	0.1-13.4 µg/L 0.45-125 µg/L, 1.00-441 µg/L	Pb1104 mg/kg Cu 161 mg/kg Zn 34162 mg/kg	(Favas et al., 2016)
<i>Eichhornia crassipes</i> <i>Chlorodesmis</i> sp <i>Cladophora</i> sp	As COD	15 days	As: 6 mg/L	COD: 50-56% As: 20-50%	(Jasrotia et al., 2017)
<i>Pteris vittata</i>	As	10 days	1000 µg/L	80%	(Huang et al., 2017)
<i>Micranthemum umbrosum</i>	As	One week	200-750 µg /L	73-60%	(Islam et al., 2017)
<i>Warnstorfia fluitans</i>	As	48-96 hours	5 or 10 µM	pH: 6.5 & 9.5 Temperature: 20 & 30 °C O ₂ :low concentration	(Sandhi et al., 2018a)
<i>Warnstorfia fluitans</i>	As	One hour	1 µM	82%	(Sandhi et al., 2018b)
<i>Salix</i> spp.	Mn Zn Cu	28 days	Mn 0.27 mg/L Zn 0.33 mg/L Cu 0.32 mg/L	Leaves Mn>Zn>Cd Stems Zn>Mn>Cu Roots Cu>Zn>Mn	(Yang et al., 2018)
<i>Potamogeton pectinatus</i> L	As ³⁺ As ⁵⁺ Hg	20 days	2 mg/L	0.1 mg/L removal	(Griboff et al., 2018)
<i>Pteris multifida</i>	Pb Cd As	24 days	Pb: 9.5 ± 1.2 mg/L Cd: 4.2 ± 0.1 mg/L As: 6.6 ± 2.0 mg/L	90% Pb 36% Cd 50% As	(Rahman et al., 2018)
<i>Azolla japonica</i> <i>Azolla pinnata</i>	Cu Zn	12 days	Cu: 7 mg/L Zn: 4 mg/L	Cu: >80% Zn: > 60%	(Akhtar et al., 2019)

<i>Salix spp.</i>	Fe Mn	28 days	4.19 mg/L 3.00 mg/L Mn	Fe	Fe (84%) Mn (69%)	(yang et al., 2019)
<i>Pistia stratiots</i>	Cu	20	Cu: 5-20 mg/L		68.75% removal	(Niazy, 2019)
<i>Monosoleum tenerum</i>	Zn, Cu, Ni, Mn, Fe	7 - 49 days	1,10, and 100 ppm		Accumulation behavior changes by concentration	(Sut et al., 2020)

2.6. Phytoremediation

Phytoremediation is a nonconventional type of phytoremediation, which is environmentally sound treatment method and its advantage as cost effective green environmental cleaning method causes it to gain interest (Olguín and Sánchez-Galván, 2010). Application of macroalgae, microalgae, and cyanobacteria was used for biotransformation or removal of metallic elements from aquatic media (Olguí, 2003; Olguín and Sánchez, 2012). Carbon dioxide of waste air and nutrients of wastewater could be removed or biologically transformed by algae and/or cyanobacteria. Phytoremediation contains highly attraction because of its ability for biomass production or biogas emission (Prajapati, 2013). This type of phytoremediation often applied for nutrient removal from animal wastewater (Olguí, 2003), leather processing effluent treatment plant (Figure 2) (Hanumantha, 2011) which contain high organic pollutants. Heavy metals could be removed by transgenic microalgae (Rajamani et al., 2007), biosorbent augmentation (Dixit and Singh, 2013), chromium by biosorbent (brown color form) of the *Kappaphycus alvarezii* (Kumar et al., 2007), Cr (VI) in presence of Calcium (Gomes and Asaeda, 2009) and Arsenic by *Cladophora algae* (Figure 3) (Jasrotia et al., 2014). Microalgae have the capacity to bind its 10% of biomass to metallic elements. Sequestering hazardous and essential metals, which often compete together is the survival mechanism for algae in polluted waters (Rajamani et al., 2007). Since most of the polluted wastewaters finally discharged to water sources. Marine algae as a high productivity and effective phytoremediator in the final destination of anthropogenic pollutants, could have a critical role in environmental protection.

Figure 2. photomicrograph shows leather processing plant effluent dissolved solid before (left) and after (right) phytoremediation by algae (Hanumantha, 2011)

Figure 3. SEM cell surface of *Cladophora* sp. at 10 kv 200X, A) control, B) Arsenic treated (Jasrotia et al., 2014)

2.7. Dendroremediation

This type of phytoremediation specified as trees application for cleaning process. The most common pollutant that have been treated by dendroremediation is TNT in the abandoned military land areas (Schoenmuth and Pestemer, 2004b). Numerous researchers illustrated the efficiency of dendroremediation for polluted soil by crude oil, landfill leachate, metallic elements (González et al., 2008) and municipal wastewater. Huge biomass production of tree species, fast growing, and high degradation capacity of woody tissues is the potentials of dendroremediation and these gigantic phytoremediators (Schoenmuth and Pestemer, 2004a, 2004b) and desirable rural landscape, especially in wildland urban interface (Langholtz et al., 2005) mentioned for dendroremediation by tree plant species. The economic viability of dendroremediation by *Eucalyptus grandis* have been assessed by optimization model in USA for municipal wastewater treatment and the collected data (considering irrigation, planting and nutrient supply) illustrate that; based on the site productivity and interest rate, for each \$1kg⁻¹ N spent in increasing the dendroremediation services, \$ 223-376 ha⁻¹ was increased in forest land value (Langholtz et al., 2005).

2.8. Cyanoremediation

This type of phytoremediation which carried out by tiny plants for wastewater, which is known as cyanobacteria, is rarely common in scientific researches (Gothalwal and Chillara, 2012) and is often specified for wastewater with high concentration of phosphates and nitrates. Meanwhile (Zhao et al., 2015), report 98% cadmium removal by *Nostoc calcicola* cyanobacterium in a novel reactor from water furthermore, (Yin et al., 2012) defined cyanoremediation as the use of cyanobacteria to remediate metallic elements. Finally, several bacterial species have been reviewed by (Mani and Kumar, 2014) throughout the cyanoremediation of metallic elements such as Cr, Cu, U, Cd, As, Fe, Mn, Se, Zn, Pb and Sr in 16 researches carried out between 2008-2013. This kind of phytoremediation also going to receive more concerns in future researches.

2.9. Mycoremediation

Fungi as vigorous agent play the main role in the decomposition of abandoned waste matter. In the biosphere, lignin is the second most abundant substrate with organic structures (Šašek et al., 2005). Presence of fungi is recognized as the essential requirement of the soil food chain (Rhodes, 2012) in supplying nourishment for terrestrial macro and microorganisms. Mycelium is the key organism throughout the breaking down the organic compounds. Bioremediation defined as the use of live organisms in order to organic compounds (could be presented as pollutants) degradation. Organic compounds bioremediation by fungi (Singh, 2006), which is recognized as mycoremediation, is a process that the enzyme present in the filamentous fungi bioremediation system properly is utilized for degradation lignin by lignin peroxidase, laccase, manganese peroxidase and H₂O₂, thus producing enzyme that could be used for peroxidase purposes similar to lignin compounds. These degradations could be augmented by supplementary carbon sources (straw, sawdust and corn cob) at the polluted areas (Rhodes, 2014) as a cleaning method for earth pollutions. Fungi bioremediation (mycoremediation) could be considered as alter tools for structures of chemical and molecular of toxic compounds to decreasing their negative impact on the environment or converting them to harmless products (Jones, 2009). The highly advanced fungi with recognized bioremediation potentials involved genera *Agrocybe* for biodegradation of hydrocarbons (Tayung & Barik, 2011). Meanwhile, four generations among the white rot fungus show massive potential for lignin compounds; these generations are *Trametes*, *Phanerochate*, *Pleurotus* and *Bjerkandra* (Singh et al., 2011). *Schizophora paradoxa* is a specific white rot fungi, which has a high tolerant to metallic elements dye, and polycyclic aromatic hydrocarbons which are found in Korea (Min et al., 2015). This finding clearly illustrates that may mycoremediation will present a wide range of opportunity for multi-contaminant polluted areas in future studies. The rapid emerging trend of research on mycoremediation shows that future researchers will concern on this treatment method for new aspects of pollutant. Numbers of mycoremediation as another short time phytoremediation are collected in Table 2.

Table 2. Mycoremediation as one of fast treatment method of pollutant removal

Fungi species	Pollutant /s	Time period	Removal degradation %	/ Reference
<i>Pleurotus ostreatus</i>	Oxyteracycline	14 days	23	(Migliore et al., 2012)
<i>Mucor hiemalis</i> Wehmer	Domestic wastewater sludge	5 days	COD 92.6 TSS 96 Turbidity 99.4	(Molla et al., 2012)

<i>Trichoderma longibrachiatum</i>	Pesticide	15 days	85	(Gangola et al., 2015)
<i>Aspergillus oryzae</i>			81	
<i>Fusarium oxysporum</i> 8-11P <i>Fusarium</i> sp.ZZZ1124	Pesticide Cypermethrin	5 days	97	(Kaur et al., 2015)
<i>Botryosphaeria laricina</i> <i>Aspergillus tamaritii</i>	Pesticide Endosulfan	4.2 day	50	(Gangola et al., 2015)
<i>Pleurotus ostreatus</i>	PAH	56 days	80.25-92.38	(Okparanma et al., 2013)
<i>Pleurotus ostreatus</i> Augmented by biochar	PAH	42 days	100	(García et al., 2015)
<i>Pleurotus eryngii</i> Augmented by tween 80	Manganese phenanthrene	15 days	92.17 93.85	(Wu et al., 2016)
<i>Aspergillus oryzae</i> FNBR_L35 <i>Fusarium</i> sp. FNBR_B7 <i>Fusarium</i> sp. FNBR_LK5 <i>Fusarium</i> sp. FNBR_BA5 <i>Aspergillus nidulans</i> FNBR_LK1 <i>Rhizomucor variabilis</i> sp. FNBR_B9 <i>Emericella</i> sp. FNBR_BA5	Arsenic	21 days	Bioaccumulated As=0.023 to 0.259 mg/L Biovolatilized As=0.23 to 6.4 mg/kg	(Singh et al., 2015)
<i>Oudemansiella radicata</i>	Cadmium PAH	10 days	93.8	(Chen et al., 2015)
<i>Coprinus comatus</i>	Cd, Cu	32 days	10.83-16.78 ppm Accumulation	(Dulay et al., 2015)
<i>Aspergillus fumigatus</i> , <i>Penicillium rubens</i>	Cd, Cr	3 days	Max 98% for Cd Max 69% for Cr	(Khan et al., 2019)
<i>Absidia cylindrospora</i> <i>Chaetomium atrobrunneum</i> <i>Coprinellus micaceus</i>	Cd Cu Pb	3 days	45% of Cd & Pb 45% Cd, Cu, & Pb 100% of Pb	(Albert et al., 2019)
<i>Ascomycota</i>	Cr, Cu. As, Fe, Mn	100 days	As 77%, Mn71% Cr60%, Cu52% Fe 56%	(Hassan et al., 2020)

Results of Table 3 illustrate that mycoremediation is a short time treatment for wide range of pollutants with high efficiency of pollutants removal or degradation in comparison with other types of phytoremediation. Based on the reports of recent studies carried out by Gangola et al. (2015) and García et al. (2015), augmentation could enhance the efficiency of pollutants degradation to highest amounts (almost 100%) throughout the mycoremediation. This type of phytoremediation is in the lab scale preliminarily studies and may require for more researches in the future. Due to rapid degradation and high adaptation by augmentation system, commercializing of this treatment technique will be valuable.

2.10. Phytosequestration

One of the suitable environmental cleaning/protection systems is plant based stabilizing (phytoimmobilization) pollutants that prevent off-site movement which is often known as phytosequestration. It causes a protection from no polluted lands as well as managing pollutions in an intensive limited area. This kind of phytoremediation could be carried out by terrestrial plant species for decontamination of soil. In a phytoremediation review paper (Reichenauer and Germida, 2008), phytosequestration is categorized as a type of phytoextraction as well as phytoaccumulation and phytoabsorption. Assimilation of atmospheric CO₂ by photosynthetic pathway in land plants for sequestration of terrestrial carbon is reported by Jansson et al. (2010) and heavy metal removal with phytosequestration is reported by Ahmad et al. (2011). This part of phytoremediation have not been extensively studied.

2.11. Phytodesalination

The plant species which adapted to live in saline environment, a salt-water marsh, locating in seawater, or a salt desert known as halophyte. 24 plant family contain 1100 halophytes which, *Amaranthaceae* is the biggest family with 353 halophytes (Flowers, 2015a). More than 40 halophyte plant species with high biomass production have been reviewed by Debez et al. (2017). On average more than 90% of the Na⁺ in halophytes is in the shoot (Flowers et al., 1977). Halophytes contain succulent leaves and/or stem that contain high content of water per unit area (Flowers, 2015b). So, harvesting of these plant species can permanently decrease salinity of treated soils.

Most recently review on halophytoremediation (Nouri et al., 2017, Nikalje et al., 2019, Cuevas et al., 2019) confirm that targets of halophyte plant species have been concentrated on agricultural issues (desalination) for protecting or improving soil in order to higher production and/or environmental cleaning subjects (heavy metals decontamination). Desalination researches mostly concentrate on A) decrease in soil salinity and sodicity, B) soil quality assessment after desalination with culture of *Hordeum vulgare* L., and C) halophyte plant capacity for accumulation of salt (Rabhi et al., 2010). Common applications of halophyte plant species are agricultural soil desalination, heavy metal decontamination and desalination (Manousaki and Kalogerakis, 2010), bioenergy production from halophyte biomass by more than 40 species (Debez et al., 2017), and recycling saline wastewater (Panta et al., 2016). Effect of halophyte plant (*Echinochloa stagninum*) compared with gypsum and ponding method for desalination of soil and livestock fodder carried out in north of Egypt. Results indicate that significant reduction of salinity collected by halophyte plant in compare with gypsum and ponding system.

Identifying dispersive soils and observing their behavior may begin early in the field by manual inspection. The soil type and the extent of soil dispersity are important factors in selecting the appropriate precaution measures. Variation in physical and chemical properties of dispersive soils have been examined by adding different additives such as lime, Zeolite, cement, pozzolan, alum, and lignosulfonate (Savas, 2016, Vakili et al., 2017, Indraratna et al., 2012). The best option must be economically sound too. Notwithstanding a combination of strategies can be simultaneously followed to achieve the most cost effective and viable action plan. Plant application for soil and water decontamination has been recognized as the most cost effective and environmentally sound technique ever (Farraji, 2014; Farraji et al., 2016). Application of halophyte plant species in saline soil (Phytodesalination), in order to improving the geotechnical properties of soil has not been assessed as capable method in dispersive soil improvement. Advantages of phytodesalination for dispersive soil may considered as following tips:

Phytodesalination as a plant-based treatment system is the cost effective treatment method ever for water, air, and soil treatment

- Adaption of this method with the hardest growing condition (high salinity, high temperature and low water availability) and weathers with providing optimum plant growth
- Nature based improvement system for soil (no chemical material addition)
- A sustainable treatment mechanism (permanently decreasing salinity of treated soils)
- Higher guaranteed method by time passing, the more plants growing, and the more desalination.
- Improving the landscaping opportunity in field of dispersive soil
- Presenting the opportunity for plant harvesting (wood and energy source)
- Accordingly, by considering the long and reasonable background for application of halophyte plant species in agricultural land area, phytodesalination may contain reasonable merits for geotechnical soil improvement. Furthermore, phytodesalination may considered as a gap of knowledge for future studies in geotechnical properties of dispersive soils.

2.11. Phytomicroremediation

Some parts of phytoremediation may concern to microbial contamination, which is suggested as Phytomicroremediation “Phyto” for the role of plant, “Micro” for microbial pollutants and “Remediation” for the process of decontamination. Treatment of microbial pollutant removal by plant species have not been fully addressed

yet. Finding capable plant species for specific targets or unsolved and new environmental problems are major parts of phytoremediation, which nowadays recognized as emerging green technology. New Zealand as spectacular ecology have some unique biodiversity, which will prepare suitable explanations for current and future environmental problem pathway, presenting plant species for phytoremediation of microbial pollution (phytomicroremediation). For this side of phytoremediation, the target goal is decontamination of soil from pathogenic microbial contents. Plant species from Myrtaceous (*Leptospermum scoparium* and *Kunzea robusta*) have the antiseptic ability for pathogenic microbial community. Two plant species from Myrtaceae had been used for controlling *Escherichia coli* and the results of this study, which were carried out in New Zealand, show E-coli concentration decreased significantly (Prosser et al., 2015). Effect of Manuka (*Leptospermum scoparium*) in biosolids amended land has been assessed by (Prosser, 2011). This finding illustrates that land application of organic waste, which may introduce microbial pollution for terrestrial media, could be treated by specific types of phytoremediator plant species, which only concentrate on protozoa microbial communities decontamination. Apart from microbial decontamination ability of *Kunzea robusta*, for N_2O fluxes from soil was investigated by Franklin (2014). All these researches carried out in New Zealand and more researches in plant ecological origin and other climate zone worldwide needed for improving and categorizing this type of phytoremediation. In terms of aesthetics, these plant species (Figure 4) are attractive for their surrounding areas. Consequently, these plant species not only showed their ability for controlling *Escherichia coli* in land areas applied for organic waste, but also may contribute to landscape attraction spectacularly in cities area. On the other hand, aerobic sequencing batch reactor (SBR) system normally used for domestic wastewater in cities worldwide, are open area and some parts of microbial communities could be sent to side areas of treatment plants. Microorganism transfer to air mainly occurs during aeration. Air bubbles bursting cause to ejecting a little film of microbial content drop to 15 cm higher than treatment surface (Warneck, 1999).

Figure 4. *Kunzea robusta* (left) and *Leptospermum scoparium* (right) as capable phyto treatment of microbial pollutants in soil

2.12. Phytoextraction

The main specification, which fundamentally forms this technique is pollutants transferring ability of plant species from underground parts to above-ground plant parts and stabilized in plant biomass (Phytostabilization). Based on the report, the woody plants are not capable of transferring track elements to upper parts in semi-arid climate. They studied four plant species and with the exception of *Populus alba*, other woody plants did not transfer heavy metals to above-ground parts (Domínguez et al., 2008). Based on the report of Robinson et al. (2003, 2019), there are very few commercial phytoextraction operations and these indicate that the efficiency of this method is low. It had been already mentioned by Robinson et al. (1998) that for Zn extraction from mine wastes by *Thlaspi caeruleum* could extract 1% of total 4% of the soil Zn content. Nevertheless, some effective utilizations from phytoextraction have been practically carried out in a natural condition for terrestrial, which polluted by acid mine drainage (Figure 6). It shows that the plant's ability for hyperaccumulation fundamentally depends on characteristic of pollutants, soil content and predicting plant habit, which will be quite hard considering several environmental conditions, climatic area of phytoextraction project, wide range of amendments, and pollutant specification, especially concentration. Based on the calculation revealed that was carried out by Robinson et al. (2015), for achieving 50% removal in total metal concentration, there is a requirement for a phytoextraction project with bioaccumulation coefficients of > 10 within 25 years extraction and consequently, phytoextraction and phytomining are impractical phytotechniques. In other words, they believe that phytomining and phytoextraction are very low-efficiency treatment method even in a very long period of time. Furthermore, those are not only eco-friendly techniques, but also they have several wide ecological footprints. In considering augmentation method for enhancing phytostabilization, such as phytofiltration which can reduce mobility of metals (As) (Bundschuh et al., 2014) and may achieve better cleaning results.

Figure 6. A field trial of polluted soil by acid mine drainage (AMD) in Shangba Village China: a) before b) after kenaf (*Hibiscus cannabinus*) growing (Xiao et al., 2008)

2.12.1 Phytomining

One of the old applications of phytoremediation (phytoextraction) is phytomining which is known as a promising extraction method for high concentration of pollutants from contaminated areas (Broadhurst et al., 2004). This plant based mining is very simply defined as using plants for precious metal extraction. Gold absorption by plants (Shacklette et al., 1970), gold in plants (Girling and Peterson, 1980) gold harvest by plant (Anderson et al., 1998) and gold uptake by plants (Anderson et al., 1999) are numbers of preliminary investigation on phytomining. Hyperaccumulator plant species are the phytoremediation macrophyte which used in phytomining process (Chaney et al., 2007; Chaney et al., 2005; Raskin et al., 1997). Phytoremediation contains some disadvantages, such as time-consuming process, limited bioaccumulation capacity, highly depended to plant growth and tolerant to metallic elements, available surface area and root depth (Farraji et al., 2016). Based on the report by Witters et al. (2012), CO₂ abatement through the phytoremediation process in polluted area should be considered as new attractive aspect of phytoremediation vs disadvantages of this green technology. By considering more than 400 hyperaccumulator plant species for Ni, phytomining of this valued metal is concerning of many researches (Zhang et al., 2016). Thus, economic value of the extracted metal is the first motive of the recovering process (Chaney, 1983). Furthermore, plant biomass and availability of decontaminated soil for normal application are other economic feasibilities of phytomining (Brooks et al., 1998). The native plants application for phytomining in aspects of practical reasons and assistant the maintenance of serpentine biodiversity successfully implemented in Albania *Alyssum murale* (Bani et al., 2015; Bani et al., 2007). Hyperaccumulator plant species can directly be used in contaminated terrestrial area (Harris et al., 2009) or in contaminated solution (aquatic media) for directly extraction precious metallic elements (Anderson et al., 1998). This technique contains two precious opportunities, namely decontamination of polluted soil and extracting expensive metallic elements. The other unique specification of phytomining is recouping possibility for phytoremediation process by the earning money from extracted metals (LaCoste et al., 2001). In the phytoextraction process, the main goal is remediation, degraded of pollutants or accumulate of metallic elements in harvestable parts of high tolerant plant species. Nevertheless, phytomining looks to recover metals from the harvestable parts of hyperaccumulator plant species (Chaney et al., 2007; Ye-Tao et al., 2012). Based on the literatures, the plant species which are selected for phytomining should have following characteristics (Brooks et al., 1998; Li et al., 2003a; Vangronsveld et al., 2009).

- Capable for producing high volume of biomass
- High tolerance to metallic elements
- Ability to growing in highly contaminated media
- High capacity to accumulation of target elements in plant parts
- They should be either natural hyperaccumulator or induced by artificial methods

The plants with aforementioned specification would be applied in mineralized soil or low-grade ore and after harvesting, biomass should be incinerated in order to bio-ore production. Meanwhile, low biomass production of most Ni hyperaccumulator plant species (*Alyssum serpyllifolium* ssp. *lustranicum*, *Noccaea goesingense*, *Alyssum bertolonii* and *A. serpyllifolium* ssp. *malacitanum*) reported by (Álvarez et al., 2016). Figure 5 shows schematic process of phytomining and Table 3 presents numbers of phytomining researches.

Figure 7. Schematic process of phytomining based on the (Brooks et al., 1998)

Table 3. Numbers of phytomining studies

Plant species /common name	Pollutants	Production	Results	Reference
<i>Biscutella laevigata</i> <i>Iberisin termedia</i>	Tl	Thallium bio-ore Energy	Acceptable concentration of Th in soil	(LaCoste et al., 1999)
<i>Iberisin termedia</i> 11 common vegetables	Tl	Thallium bio-ore Energy	Common vegetables are not suitable <i>Iberisin termedia</i> in 5 sequential	(LaCoste et al., 2001)
Green cabbage > carrot > chili > Chinese cabbage > rice > corn Respectively Tl concentration	Tl	Soil cleaning + health care and Tl mining	Green cabbage concentrate 500 mg/kg dry wt Thallium	(Xiao et al., 2004)
<i>Alyssum murale</i>	Ni	6.3 t ha ⁻¹ biomass + 9129 mgkg ⁻¹ Ni in shoots	Extensive phytomining augmented by fertilization	(Bani et al., 2007)
<i>Cicer arietinum</i> <i>Piptatherum milliaceum</i> <i>Lygeum spartum</i>	Pb Cd Cu Zn	Saving agricultural areas	Highest concentration in the roots of <i>P. milliaceum</i>	(Conesa et al., 2009)
<i>Berkheya coddii</i> <i>Bressica juncea</i>	Ni	Economic feasibility by phytomining	Profitability is very sensitive to the price of metal and the extraction of target metal	(Harris et al., 2009)
<i>Alyssum corsicum</i> <i>Alyssum malacitanum</i> <i>Alyssum murale</i> <i>Noccaea goesingense</i>	Ni	Auxin have positive effect on Ni accumulation	Biomass increasing by hormone augmentation have no linear correlation with accumulated Ni	(Cabello et al., 2014b)
<i>Alyssum murale</i>	Ni	30 times biomass production and 100 times Ni accumulation	Positive effect of Weed control Time optimized cropping Fertilizing on biomass production	(Bani et al., 2015)
<i>Bornmuellera tymphaea</i> and <i>Noccaea tymphaea</i>	Ni	Type of planting Mixed planting positive effect illustrated	Combination of two hyperaccumulator have positive effect on Ni hyperaccumulation	(Rue et al., 2015)
<i>Bornmuellera typhaea</i> – <i>Noccaea tymphaea</i>	Ni	Amount of extracted Ni, 66.4%	PGPR have positive effect on Ni accumulation	(Durand et al., 2015)

<i>Bornmuellera murale</i>	<i>typhaea-alyssum</i>		in root and 79.6% in shoots		
<i>Alyssum serpyllifolium</i>	ssp. <i>Ni</i>		Application of the organic wastes as amendment	Compost as organic amendment could be considered as incorporated into phytomining	(Álvarez et al., 2016)
<i>A. serpyllifolium</i>	ssp. <i>malacitanum</i>				
<i>Noccaea goesingense</i>					
<i>Alyssum bertolonii</i>					
<i>Odontarrhena bracteata</i> , <i>O. inflata</i> , <i>O. serpyllifolia</i>	<i>Ni</i>		Significant effect of plant species proved	Manure amendment and Bacterial inoculation enhanced extracted Ni	(Ghasemi et al., 2018)
<i>Bornmuellera emarginata</i>	<i>Ni</i>		2.9 kg/ha	Compost amended plots	(Cerdeira-Pérez et al., 2019)
<i>Noccaea caerulea</i>			1.9 kg/ha	produced higher biomass	
<i>Odontarrhena muralis</i>			2.3 kg/ha		
<i>Odontarrhena serpyllifolia</i> .			-		
<i>Odontarrhena chalcidica</i>	<i>Ni</i>		55kg/ha	Sulphur implementation	(Rosenkranz et al., 2019)
<i>Noccaea goesingensis</i>			36kg/ha	High density planting	
<i>Odontarrhena chalcidica</i>	<i>Ni</i>		Max uptake 26.8 g kg ⁻¹ Ni	Positive effect of fertilizing for higher Ni uptake	(Tognacchini et al., 2020)

Based on the report of Australian researchers (Harris et al., 2009), in the future phytomining appears to be the most viable technique, where there are comparatively extremely high metallic elements concentration especially around the abandoned mines and plants, which process metals. In Portugal, researches of Alves et al. (2019) indicated additional income source for local farmers in Ni agromining by *Alyssum serpyllifolium* subsp. *Lusitanicum*. Nevertheless, New Zealand scientists, Robinson et al. (2015) illustrate that: this phytotechnology suffers from low efficiency of precious metals extraction rates. Meanwhile, Álvarez et al. (2016) indicate that organic wastes amendment causes the recycling of these residues through the phytomining as enhancing advantages of this cleaning method. Positive effect of cropping, fertilization, and weed control through the Ni phytomining has increased biomass production to 30 times and 100 times of phytoextracted Ni in comparison with normal growing (Bani et al., 2015). *Arthrobacter nicotinovorans* SA40 was reported as rhizobacteria for augmenting Ni uptake and accumulation (Cabello et al., 2014a). Application of plant hormones such as Gibberellins and Cytokinins reduces metal accumulation (Cabello et al., 2014b). Finally, “Agromining” concept are presented by Van Der Ent et al. (2015), a team of expert scientists from Australia, Canada, China, France, New Caledonia, New Zealand and United States, as future policy for decontamination method by agro-plant application against “phytomining “. In this method, all process of planting, fertilizing, weed control, cropping and final harvesting will be planned as an agricultural farming process. Thus, future technical improvement and scientific research, such as enhancing metal yield amendment techniques (Álvarez et al., 2016), productivity by co-cropping of legume (Jiang et al., 2015) or increasing purity of final production (Zhang et al., 2016) as well as the economic value of metallic elements and human requirement will assume the role of agromining as improved and advanced phytomining.

3. FUDAMENTAL OD PHYTOREMEDIATION

3.1. Phytoaccumulation

Phytoaccumulation defined as accumulation of trace elements in phytoremediator plant species. Hazardous metallic element accumulation from aquatic media with *Lemna minor* L. (Zayed et al., 1998), *Eichhornia crassipes* (Zhu et al., 1999), *Myriophyllum aquaticum*, *Mentha aquatic* and *Ludwigina palustris* (Kamal et al., 2004) and terrestrial plant species such as *Helianthus annuus*, *Nicotiana tabacum* and *Vetiveria zizanioides* (Boonyapookana et al., 2005), *Solanum tuberosum* L. (Baghour et al., 2001) and *Brassica juncea* (Shahandeh and Hossner, 2000). These researchers finally report the selectivity or ordering of trace elements by plant species such as Hg > Fe > Cu > Zn (Kamal et al., 2004) or Cu > Se > Pb > Cd > Ni > Cr (Zayed et al., 1998) in presenting eligible plant species for specific pollutant removal. By considering accumulated metallic elements in root, shoots, and leaves as under grand and upper grand parts of the plant, phytoaccumulation studies may present new hyperaccumulators for future application. This section of phytoremediation has been fully addressed in literatures both aquatic and terrestrial media and the collected information by phytoaccumulation is used as input data for several other scientific lab scales, field or full-scale studies. Phytoaccumulation categorized as phytoextraction by (Reichenauer and Germida, 2008).

3.2. Hyperaccumulation

Contaminated soils are the major source of heavy metals uptake by plants. Toxic effects of heavy metals cause several serious physiological and structural damages for plants. Tolerance to low or high concentration of heavy metals depends on plant physiology and genetics. Finding naturally grown species in highly polluted soils could be considered as the usual method for distinguishing and collecting hyperaccumulator plants. In the accumulation of metallic elements, the characteristics of a hyperaccumulator species are at least 100 times more than non-hyperaccumulator species (Brooks and Farago, 1994). Meanwhile, an unusual hyperaccumulator with more than 500 µg/g dry mass (*Iberis intermedia*) was found in France (Leblanc et al., 1999). Numbers of hyperaccumulator plant species increased from 400 species (Baker et al., 2000) to 500 species by Ma et al. (2001). This emerging issue is continued in finding specific hyperaccumulator for single heavy metal. Nowadays, 450 Ni hyperaccumulators (Van der Ent et al., 2013a) and the vast majority of these plant species which are known as natural hyperaccumulators of Ni, are endemic to soil developed over rocks that named “ultramafic rocks” with high concentration of metallic elements such as Co, Cr and Ni (Reeves, 2006). In another case, 400 Cd hyperaccumulator plant species reported by (Hakeem et al., 2014).

The process of phytoextraction and phytomining by natural hyperaccumulator plant species can effectively cause decontamination of polluted soils (Raskin et al., 1997). Lack of scientific knowledge about basic plant species process is the main limitation of this high potential of natural hyperaccumulator for decontamination of polluted media (Pilon-Smits, 2005). Genetic modification as basement of hyperaccumulation process and traditional breeding systems as improving the specification method, are two main aspects of a clear picture, which will give for mechanism of metals the entrance to plant roots and the process, which finally cause the translocation of metallic elements to upper parts of hyperaccumulator plants (McGrath and Zhao, 2003).

There are new types of hyperaccumulation system, which are a non-hyperaccumulator species and industrial crop production species with hyperaccumulator behavior. This type of plants naturally could not be considered as hyperaccumulator. Nevertheless, with augmentation of nutrients through the growing, addition of specific adsorbent such as biochar, these augmentations could be applicable in preparing better circumstances for higher biomass production by natural hyperaccumulator or decreasing toxicity of heavy metals for normal, moderate or crop species to present hyperaccumulation behaviors. Biochar application as a simple soil augmentation could decrease available heavy metals for non-hyperaccumulator plant species, such as *Zea mays* while *Lolium perenne* and increase root specific surface in order to root proliferation (Rees et al., 2016). Therefore, it can be a suitable application of crop plants as high uptake species with extremely high biomass production, which finally cause to higher and efficiency of heavy metal extraction in shorter time.

3.3. Mechanisms of metals accumulation

The major mechanisms involving hyperaccumulation of metallic element are:

- Roots and microbes interaction cause to bioactivation of metallic elements in rhizosphere
- Metal sequestration by tonoplast transporters in the vacuole
- In the plasma membranes of hyperaccumulator species, there are transporter organism which enhance heavy metals uptake
- Ligands such as protein with metal binding, phytochelatin, and metallothioneins in the cell walls of the cytoplasm make a chelation in order to metal detoxification (Yang et al., 2005)
- The metallothionein mechanism could be considered as a suitable stress response in the context of metallic elements (Janssens et al., 2009)

Cadmium and lead as high toxic heavy metals, which have a harmful effect on plants and animals even in low concentration, will be assessed here as metallic elements. A concentration of 100 mg/kg d.wt (0.01%) is a base volume of Cd for a hyperaccumulator plant species (Baker et al., 2000). Only *Sedum alfredii* (Sun et al., 2007) and *Thlaspi caerulea* (Basic et al., 2006) are plant species, which are reported as Cd hyperaccumulator. *Thlaspi caerulea*, which are grown in metal polluted soil, had a high root to shoot ratio and higher biomass production in comparison with same species that were growing in non-polluted soils (Dechamps et al., 2005). Cadmium accumulation could be seen as polymorphism characteristics in *Thlaspi caerulea* which is a suitable case for increasing knowledge of hyperaccumulation mechanism and based on the report of Basic et al. (2006), molecular data could be used for distinguishing these types of hyperaccumulator plants. Translocation of cadmium from root to shoot usually carried out by the xylem and this process driven by leaf transpiration (Ueno et al., 2008; Uruguchi et al., 2009). Furthermore, positive effect of transpiration on Cd translocation as a clear relationship between two physiological activities of the plant is reported for *Phytolacca Americana* by (Xiaoqing et al., 2010). Process of root

uptaking of Cd and loading in xylem and finally translocation to above ground (shoots), symplastic pathway are more contributed than apoplastic bypass. It suggested by Qin et al. (2013) that high mobility for Cd in both the phloem, xylem and stems have a major role in transferring through these pathways. Concentration of Cd in plant parts is by order of shoots > roots > leaves (Kirkham, 2006; Sun et al., 2007). In a recently mechanism study of hyperaccumulation process, Liu et al. (2016) presented an active-passive pathway for Cd uptaking in tobacco. Figure 7 illustrates two-step mechanism for cadmium translocation in *Nicotiana tabacum* L. As it can be seen in translocation of Cd from roots to stem, the main role belongs to leaves transpiration.

Figure 8. Two-step translocation mechanism for Cd in tobacco plants (Liu et al., 2016)

There is no biological function for lead (Pb) in plant, however, this non-biodegradable high toxic metallic element accumulated by plant in high concentration volume in shoots > roots (Farraji et al., 2014). Furthermore, there is a significant correlation between Pb concentration in plants tissues and lead concentration in soil (Kabata-Pendias, 2010). Only the plant species with more than 1% lead in their upper part could be considered as qualified high biomass plant species, such as *Sesbania drummondii* for Pb extraction as hyperaccumulator (Sahi et al., 2002). Lead is the most immobile heavy metal compare to Cd, Cu, Zn, Ni and Cr (Kumar et al., 1995). On the other hand, attendance of organic matters decrease the risk of contamination transport to the groundwater (Mohajeri et al., 2018) so, for enhancing translocation of lead in soil media and plant tissues, some amendments such as chelators beside acidifier could be a suitable method (Salt et al., 1995). In a research on *Salvinia minima* as hyperaccumulator of Pb and Cd (Sánchez-Galván et al., 2008), intracellular accumulation and bioadsorption are mentioned as contribute mechanisms for hyperaccumulation process. It is necessary to shade more light on the uptake mechanism by genome studies (Janssens et al., 2009).

4. CONCLUSION

Phytoremediation as an emerging technology in environmental cleaning is going to be considered as one of major treatment or post treatment methods for improving soil and water quality (Farraji et al., 2020). Phytoremediation as a technique follows a naturalistic style of adaptation with pollutants. Atmospheric, terrestrial and aquatic media could be the targets of decontamination for this technique. Wide range of contaminants contains degradable and/or non-degradable, organic and/or inorganic could be treated by this technique. Furthermore, the concentration of pollutants in this green treatment system is extremely wide. In other words, for numerous type and/or concentration of pollutants, phytoremediation as treatment methods, has the uniqueness of characteristics, such as sustainable and cost effective. Phytoremediation is highly adaptive as co-treatment (Jesus et al., 2015), electro-treatment (Cameselle & Gouveia, (2019), and post treatment (Schwantes et al., 2019). The most important factor in the application of this eco-friendly technology is the proper selection of suitable phytoremediators and preparing promotional augmentation for enhancing the efficiency in comfortable circumstances. As a matter of fact, even after two decades of utilization from phytoremediation for environmental cleaning, there is no union system of standard terms and application method, plant density and even definition of applied words, which causes facing on enormous non-comparative researches on phytoremediation. When Salt et al. (1995) define three subsets (1) phytoextraction, (2) Rhizofiltration and (3) phytostabilization for phytoremediation, it was unthinkable to them that in approximately two decades subsets will rapidly increase. Strict requirement seems to be needed for standardization and classification for all types and process of these treatment methods in order to put it in a framework of a global recognized organization. There are many black and white observation about this technique, while the attraction of unknown specification and novel abilities of this “phyto” base treatment converted it into one of the most highly cited issues in researches. This treatment system is widely applied in some commercial cases such as landfill covering and is going to be major

treatment method for municipal wastewater in few future. On the other hand, this technique suffers from long time requirement and high sensitivity to the concentration of pollutants, especially complex metallic elements and suspended solids. Furthermore, utilization of this technique as economically feasible treating technique in terrestrial phytoextraction is faced with fundamental arguments. Nowadays, many new aspects of the knowledge, such as augmentation (microorganisms) and amendment techniques (nutrients and organic matters) for promoting uptake efficiency, are going to be a constant part of phytoremediation as well as planting, harvesting, weed control, and multicultural utilization of phytoremediator plant species, which are often considered in phytoremediation plans. There are several unknown and mysteries sides about this technique which future studies will need to be concerned about to give a clear picture on phytoremediation.

1. The following tips may be considered as future research area:
2. Finding specific phytoremediation technique for high suspended solid wastewater
3. Finding natural multi metallic element hyperaccumulator plant species
4. Optimization of nutrients, mycorrhiza and promoter augmentation
5. Enhancing the efficiency of multipollutant removal in natural condition
6. Specifying fast and high performance phytoremediation techniques
7. Agricultural application of contaminated areas
8. Biomass management for sustainable phytoremediation process
9. Air / noise pollution control in industrial and municipal regions by phytoremediation

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