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REVIEW ARTICLE

Strategies and prospects in the recovery of contaminated soils by phytoremediation: an updated overview

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ABSTRACT

The contamination of soils and groundwater has attracted worldwide attention, since many contaminants are poorly biodegradable and can accumulate in living organisms, causing implications for plants, animals, and human health. The high cost of conventional remediation processes stimulates research for the development of innovative and more sustainable techniques. Likewise, phytoremediation is a cheap technology that uses plants to absorb, transform, and detoxify contaminants through *in situ* (phytoextraction, phytotransformation, and phytovolatilization) and *ex situ* mechanisms (phytostabilization and phytostimulation). Recently, phytoremediation has been adopted as a more profitable technique than physicochemical processes. Otherwise, the existence of variables, such as interactions between climate, soil, and plants, requires analysis methods for its implementation, which ensure the reduction of time and cost and improve its efficiency. Research on the application of different phytoremediation techniques is still in progress, and therefore, this study evaluated the main advantages of phytoremediation through a literature overview, comparing the most adequate remediation models in terms of economic, social, and environmental aspects.

Highlighted Conclusions

1. Phytoremediation consists of the use of plants and their associated microbes for environmental cleanup and recovery of contaminate soil.
2. Phytoremediation promotes social-economics benefits comparing to the conventional techniques, and ensures sustainability in environmental rehabilitation.

INTRODUCTION

Population, technological development, and urbanization increase the demand for natural resources (Gouveia 2012). These aspects are responsible for the high generation of waste, which is directly related to population growth and has a propensity to affect the economic, environmental, and safety aspects (Abdolali et al. 2017; Bhatnagar et al. 2015). From an environmental perspective, the contamination of soils and water is one of the main problems caused by the incorrect disposal of solid and liquid residues from agriculture, industry, and domestic activities (Marques et al. 2011). According to the Food and Agriculture Organization (FAO), there are more than 648 thousand metric areas potentially contaminated by heavy metals and mineral oils in Europe (Food and Agriculture Organization of the United Nations 2015). Moreover, the United States Government Accountability Office (USGAO) invested approximately US$ 23 million in the treatment of areas contaminated with aromatic compounds, solvents, and heavy metals (United States Government Accountability Office 2015). In Brazil, only a small part of the contaminated areas is derived from agricultural activities, and the highest contamination level results from industrial and mining activities (Blanco et al. 2020; Goncalves et al. 2014). Therefore, one of the biggest challenges for underdeveloped countries in the correct management of contaminated areas can be associated with non-compliance of laws and few economic resources (Coulon et al. 2016; Ferreira et al. 2020; Sam et al. 2016).

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The disposal of aromatic compounds, solvents, toxic substances, and heavy metals raises soil contamination levels, generating complications to the environment (Dudai et al. 2018). The mechanisms for the treatment of pollutants have been constantly studied, such as electrochemical methods, reverse osmosis, advanced oxidative processes, and bioremediation (Abdolali et al. 2017; De Vasconcellos and Da Fonseca 2017; Gherasim et al. 2013). In the case of bioremediation, this technique employs *in situ* or *ex situ* biological mechanisms processes (Marques et al. 2011). *Ex situ* methods can be applied for contaminated areas, including extraction for treatment through physicochemical methods; however, all these technologies involve expenses, labor, and long-term operating costs. Otherwise, *in situ* tools are associated with the use of plants and microbiological mechanisms associated with the rhizosphere to degrade contaminants (Mishra and Chandra 2022; Susarla et al. 2002).

Therefore, phytoremediation is one of the areas of bioremediation widely used for decontamination of soils and waters (Merkl et al. 2006). Phytoremediation is usually used for the treatment of various contaminants, which minimizes the generation of secondary residues and is considered a low-cost method (Derakhshan Nejad et al. 2018; Dudai et al. 2018). Moreover, the use of phytoremediation for decontamination of hydrocarbons, solvents, pesticides, heavy metals, and leached liquids demonstrates positive results in experimental trials (Ikeura et al. 2016; Kogbara et al. 2016; Susarla et al. 2002; Zhu et al. 2017). Despite its efficiency against various contaminants, it is important to highlight that not all plant species can be used for phytoremediation due to the specificity of growth in contaminated environments (Marques et al. 2011). Each plant species absorbs a certain type of toxic substance and promotes conditions for the development of rhizosphere microbiomes (Arslan et al. 2017; Fatima et al. 2016). Phytoremediation presents a high potential for the recovery of contaminated areas due to the great biodiversity and climate conditions, which are advantages for the treatment of contaminated areas (Zancheta et al. 2011). Otherwise, there are few large-scale applications of phytoremediation, which makes it difficult to propose the effectiveness of this technology by environmental agencies and companies (Nedjimi 2021).

Based on the abovementioned and due to the numerous positive characteristics of phytoremediation, the focuses of this critical review were *i)* to evaluate the phytoremediation mechanisms in the treatment of contaminated areas; *ii)* to compare phytoremediation with conventional techniques; and *iii)* to demonstrate the socioeconomic barriers in the application of phytoremediation. In this context, our review sought to answer the following questions: *i)* Can phytoremediation be applied as an effective decontamination tool? *ii)* Can phytoremediation be a low-cost method when compared with other remediation techniques? and *iii)* what are the socioeconomic barriers to the application of phytoremediation?

BIBLIOGRAPHIC BACKGROUND OF PHYTOREMEDIATION

The data collection used for the literature review was based on scientific publications published and indexed in the Science Citation Index Expanded (SCI-E) of the Clarivate Analytics' ISI and Scientific Electronic Library Online (SciELO). The following logic operation was used in the Web of Science©: “phytoremediation” AND “soil”. Through this search query, it was possible to refine the publications based on selected words included in the title, abstract, and author's keywords of each document. The research was performed for the period between 2015 and 2021 using a filter for “article” and “review”. In total, 5,936 documents (5,431 articles and 505 reviews) were published over the selected timespan. The documents obtained were exported for VosViewer© software (version 1.6.14) to perform a bibliometric analysis (van Eck and Waltman 2010). The systematic search resulted in 9522 keywords. The most frequent keywords in the research field were *phytoremediation*, *heavy metals*, *cadmium*, *phytoextraction*, *bioremediation*, *phytostabilization*, *lead*, *soil*, *biochar*, *arsenic*, and *hyperaccumulator*. Figure 1 presents the maps based on the 50 main keywords, and the connections among them (i.e., clusters) were generated. The term map resulted in seven different clusters, where the most important is the red with 12 keywords, where the central keyword *phytoremediation* appears. In addition, the most important research areas were *Environmental Sciences Ecology*, *Engineering*, *Agriculture*, *Plant Sciences*, and *Toxicology*, which are directly associated with the main keywords used. Hence, from the bibliometric results, it is possible to highlight the main topics studied in phytoremediation, which were used to address the topics of the highest priority.

EVALUATION OF PHYTOREMEDIATION MECHANISMS FOR THE TREATMENT OF CONTAMINATED AREAS

Phytoremediation consists of the use of plants and their associated microbes for environmental cleanup (Pilon-Smits 2005; Salt et al. 1998). Phytoremediation processes aim to remove pollutants, minimize soil erosion, and reduce the transfer of toxic substances to soil and groundwater (Jaskulak et al. 2020). In phytoremediation, vegetables can act directly or indirectly (Rai et al. 2020; Tavares et al. 2013). Figure 2 shows the direct and indirect mechanisms of phytoremediation (Souza et al. 2020). Figure 3 shows a schematic representation of phytoremediation (Chandra et al. 2017).

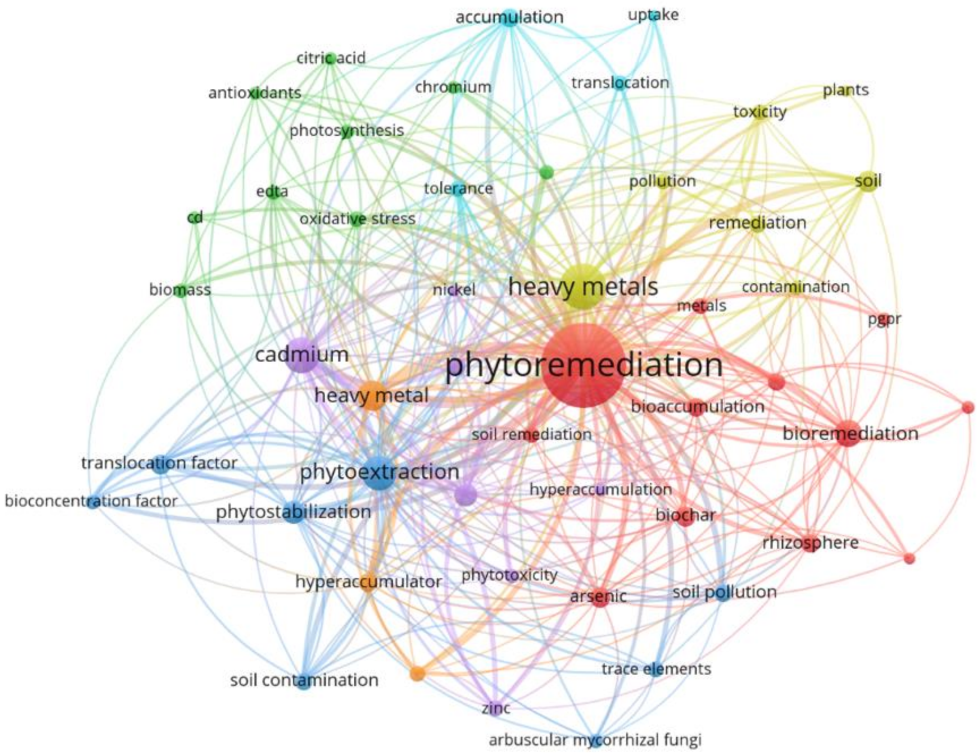

Figure 1. Bibliometric analysis of phytoremediation - Term map based on different clusters. Different colors represent the terms belonging to different clusters. The connecting lines indicate the strongest co-occurrence links between terms. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article).

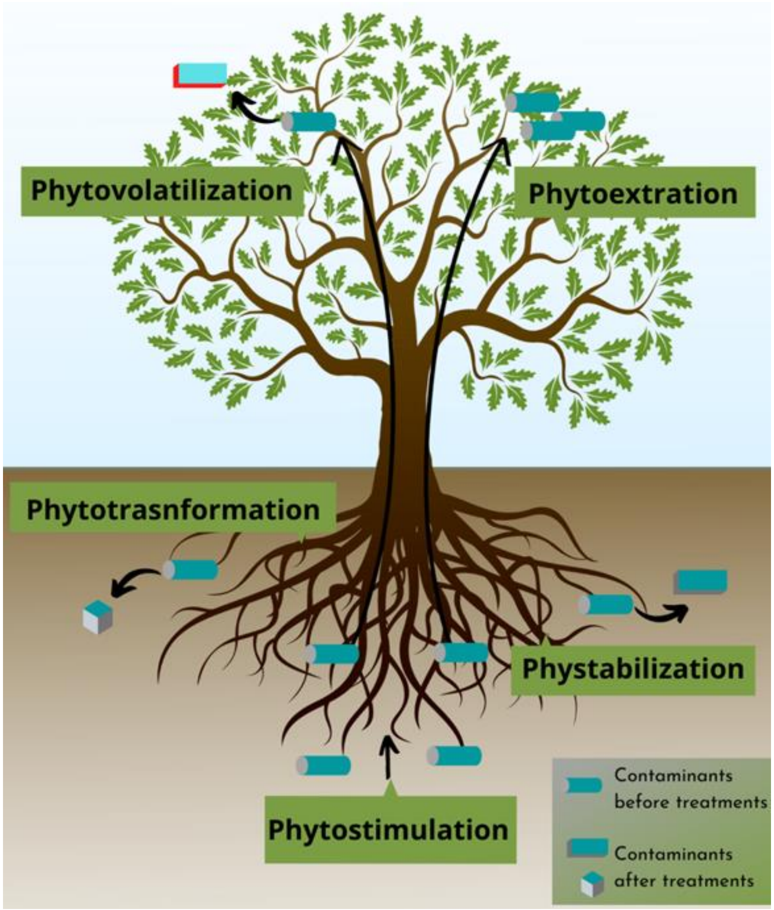

Figure 2. Mechanism of phytoremediation. Adapted from Souza et al. (2020).

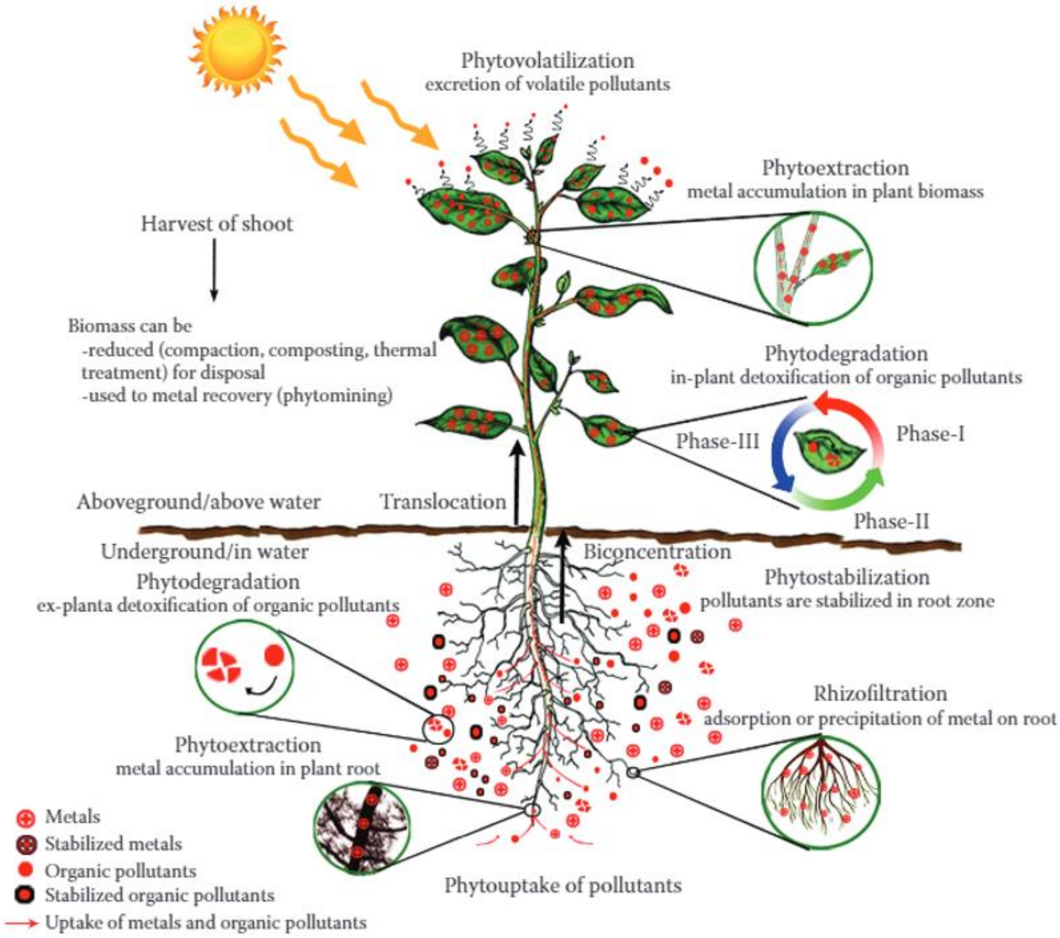

Figure 3. Schematic representation of phytoremediation. Reproduced from Chandra, Dubey and Kumar (2017).

In direct remediation, contaminants accumulate through absorption and are metabolized inside the plant. The direct mechanisms are phytoextraction, phytotransformation, and phytovolatilization. Phytoextraction is related to the plant's ability to absorb soil contaminants and store them in its roots or tissues, requiring long periods to reduce contaminants (Auchterlonie et al. 2021; Witters et al. 2012). Phytotransformation is normally used on organic compounds, where the plant absorbs contaminants from water or soil metabolizing on the surface or inside. Phytovolatilization is based on the absorption of contaminants by plants, which metabolizes them inside or in cooperation with rhizosphere microorganisms, releasing contaminants into volatile forms (Mejía et al. 2014; Pinheiro 2015; Zancheta et al. 2011).

In indirect phytoremediation, vegetables extract contaminants from groundwater, performing external degradation, reducing the source of contamination, and releasing compounds that favor microbial activity in the rhizosphere (Fellet and Marchiol 2011; Ting et al. 2018; Yan et al. 2020). The indirect mechanisms are *i)* phytostabilization – the ability of plants to reduce the mobility or migration of contaminants present in the soil – this mechanism depends on the incorporation of the compound in soil humus or lignin; and *ii)* phytostimulation – plants perform microbial degradation of contaminants (De Marco et al. 2017; Melo et al. 2010; Santos et al. 2007). However, the choice of mechanisms can influence some variables, such as pH, humidity, and nutrients, which can cause disadvantages and increase the recovery time (Yan et al. 2020). This diversification promotes indicators that allow the choice of the best mechanism for phytoremediation (Babu et al. 2021). These mechanisms are shown in Table 1, where contaminants are associated with the direct and indirect phytoremediation methods. The mechanisms of phytoextraction, phytotransformation, and phytovolatilization have better remediation effects on heavy metals than indirect approaches; however, both have positive interactions with organic substances (Mejía et al. 2014).

Phytoremediation mechanisms present effectiveness in their processes. For this, the plants need some characteristics: *i)* absorption capacity, metabolization, and contaminant tolerance; *ii)* contaminant retention in roots; *iii)* high growth rate and biomass production; *iv)* easy harvesting when removal is needed; *v)* resistance to pests and diseases; and *vi)* plant development in diverse environments. In addition, phytoremediation may be limited by some technical factors, such as the high toxicity of contaminants on plants, slow decontamination (because plants do not present biochemical functions to achieve total removal of contaminants), climatic conditions, and the life cycle of the plant species. Finally, contaminated biomass should receive adequate treatment and disposal and the limitation caused by the depth of the rhizosphere (Cabral et al. 2010; Ferreira and Lamas 2010; Jesus et al. 2009; Marques et al. 2011; Melo et al. 2010; Pires et al. 2003; Siebeneichler et al. 2008).

Table 1. Phytoremediation classification for different contaminants. Adapted from Mejía et al. (Mejía et al. 2014).

Phytoremediation classification		Type	Contaminants
Direct	Phytoextraction	Inorganic	Ag, Cd, Cr, Cs, Cu, Hg, Mn, Mo, Ni, Pb, Pu, U, Zn
	Phytotransformation	Organic	Hydrocarbons, PCP, TCE e PCB
	Phytovolatilization	Inorganic	Se and Hg
Indirect	Phytostabilization	Inorganic	As, Cd, Cr, Cu, Hg, Pb, and Zn
	Phytostimulation	Organic	Hydrocarbons, PCP, TCE e PCB

Label: PCP, pentachlorophenol; PCB, polychlorinated biphenyls; TCE, trichloroethylene.

Phytoremediation can be implemented in different scenarios for the treatment of contaminated areas, a step that should be analyzed according to the objectives and variables of the site (Mishra et al., 2020). The analysis of mechanisms may favor the process for choosing phytoremediation, which should evaluate the interaction between plants, contaminants, and soil (Brehm et al. 2013; Jaskulak et al. 2020). Figure 4 shows the possible phytoremediation approaches to protect the ecosystem from pollution. Through these mechanisms, it is possible to verify the interactions between plants and soil, that is, an indicator of plant species adaptation. Phytoremediation can be modeled by the accumulation of contaminants in the plant by metabolization and monitoring the soil and water of contaminated areas (Hasanuzzaman et al. 2017; Mandal et al. 2014). The selection of mechanisms for phytoremediation planning depends on the objectives, which are associated with the advantages and disadvantages of each model applied, for the complete understanding of the level of results (Janani et al. 2019; Kumar Yadav et al. 2018; Muthusaravanan et al. 2018).

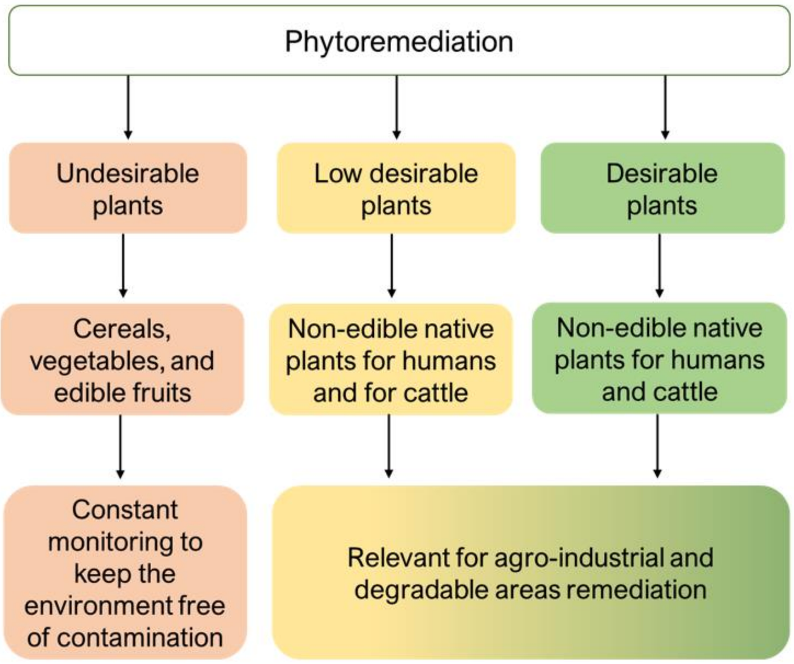

Figure 4. Possible phytoremediation approaches to protect the ecosystem from pollution.

PHYTOREMEDIATION *VERSUS* CONVENTIONAL TECHNIQUES

Several remediation techniques have been developed and implemented to provide new possibilities to treat soil and water from contaminated areas (Gong et al. 2018). The application of phytoremediation techniques can promote positive benefits: *i)* alter the physicochemical properties of contaminated soil; *ii)* release biomolecules from the plant, increasing the amount of organic carbon; *iii)* improve aeration, which increases soil porosity; *iv)* decrease the movement of chemical contaminants; and *v)* reduce the migration of pollutants to groundwater. Through these aspects, phytoremediation stands out due to its varied applications (Jaskulak et al. 2020; Janani et al. 2019).

Conventional techniques are strong competitors of phytoremediation and can be classified as physical, chemical, or biological (Figure 5). The best cost–benefit ratio is sought, although in some cases they may require a specific technique with higher costs. Therefore, one of the main remediation techniques represents its applications for the treatment of different types of contaminants (Kafle et al. 2022). Among them, techniques such as solidification and stabilization promote the exchange of physical characteristics in the residue, helping to reduce the mobility of contaminants through thermal and chemical interactions and promoting a physical barrier to leaching. In these processes, some binder material can be used to solidify contaminants such as fly ash, lime, and polymers (Brehm et al. 2013).

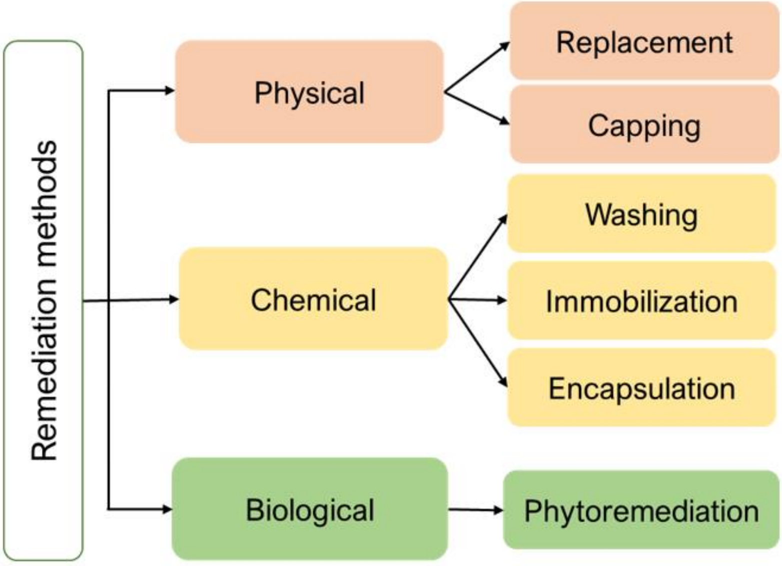

Figure 5. Illustration of the physical, chemical, and biological remediation methods.

The pump and treat remediation technique is the most used for contaminated groundwater. For this method, one or more extraction wells are used to remove contaminated water and are pumped from the subsoil for the treatment operation, which may consist of air removal, carbon adsorption, or a biological treatment system (Brusseau 2019). When applied to saturated subsurface systems, such as aquifers, the pump and treat method promotes *in situ* techniques for contaminant removal (Freire et al. 2014).

Another common technique used in the remediation of contaminated soils is high-temperature thermal desorption. These high-temperature methods offer rapid remediation, with case studies showing soil and groundwater treatment within six weeks (Sörengård et al. 2020). It is a physical remediation technology that uses volatilization and desorption as the main mechanisms for removing contaminants (Brusseau 2019). However, the costs of using this technique are generally high compared to other methods (Ruiz et al. 2012).

Treatment through bioppiling is a large-scale technology and is a hybrid system of landfarming and composting, in which the excavated soils are mixed with altered soils and arranged in a treatment area containing systems for the collection of leachates. It is typically used to reduce hydrocarbon concentrations in excavated soils using biodegradation. The biopile promotes a favorable environment for the development of aerobic and anaerobic microorganisms under controlled conditions (Amaral et al. 2008). Additionally, the insulation of the material prevents the dispersion of particles that can carry the contaminant and eventually microorganisms (Bisognin et al. 2018).

Nonetheless, bioremediation is a technique composed of microorganisms responsible for reducing or transforming certain pollutants, such as pesticides, polymers, drugs, and plastic waste from contaminated areas, through biological degradation techniques (Brehm et al. 2013). Bioremediation requires constant monitoring to ensure that it is not applied in the remediation of soils with radioactive substances and inorganic acids, which limits its application (Juwarkar et al. 2010).

The cost linked with each of these main remediation techniques, applied in different types of treatment (Table 2), shows that physicochemical remediation technologies have higher costs concerning biological techniques (bioremediation/phytoremediation). It can be observed that among all the remediation technologies, phytoremediation is the one that shows the lowest costs of implementation and maintenance, with operation costs ranging from 19 to 78 USD m^{-3}. This cost comparison varies depending on the location of the application, the technology employed, and local resources. In addition to costs, physicochemical remediation techniques influence soil properties, such as fertility and biodiversity. However, techniques such as phytoremediation are economically viable, environmentally correct, and sustainable for large-scale application (Freire et al. 2014; Khalid et al. 2017; Liu et al. 2018; Yu et al. 2020).

Table 2. Comparison of costs (USD m^{-3}) of different remediation techniques.

Remediation technology	Cost (USD m^{-3})	Reference
Solidification/Stabilization	87 – 190	(Chen and Chiou 2008)
Pump and treat	240 – 813	(Chen and Chiou 2008; Inoue and Katayama 2011)
Thermal desorption	81 – 252	(Inoue and Katayama 2011)
Biopile *in situ*	130 – 260	(Inoue and Katayama 2011)
Bioremediation	30 – 100	(Krug et al. 2009)
Phytoremediation	19 – 78	(Chen and Chiou 2008; Wan et al. 2016)

BENEFITS AND DRAWBACKS OF PHYTOREMEDIATION

Figure 6 presents the benefits and drawbacks of phytoremediation (Sierra et al. 2021). The following benefits are highlighted for the application of phytoremediation technology (Bianchi et al. 2011; Placek et al. 2016; Wu et al. 2014): *i)* low operating cost; *ii)* high community acceptance; *iii)* easy operation; *iv)* sustainable technique; *v)* applicable to a large contaminated area; *vi)* prevention of erosion; *vii)* prevention of leaching; and *viii)* avoidance of the spread of toxic substances to surrounding areas. However, phytoremediation presents several drawbacks (Farraji et al. 2016; Gunarathne et al. 2019; G. Singh et al. 2022; S. Singh et al. 2022): *i)* long time consuming process, as plants take time to grow; *ii)* depth of soil for treatment is limited due to short length of plant roots; *iii)* the toxicity of contaminants increased too much that it can be toxic to plants; *iv)* due to the presence of contaminants in plant tissue, the entrance of contaminants to the food chain is still possible by animals/insects that eat plant materials.

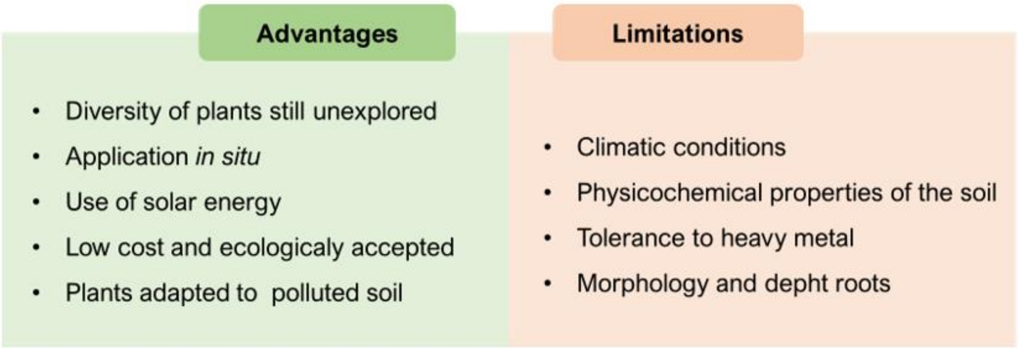

Figure 6. Advantages and limitations in phytoremediation. Adapted from Sierra, Muñoz and Sokolski (2021).

SOCIAL AND ECONOMIC BARRIERS IN THE APPLICATION OF PHYTOREMEDIATION

Among the main social barriers, the lack of technical and social information leads to the development of regulatory instruments that disfavor biological remediation techniques. The application of conventional techniques has greater investment by environmental agencies, increasing competition with phytoremediation, which has limited investments since it is an innovative technology (Marques et al. 2011). Barriers are also associated with the use of genetically modified crops and the risk these crops pose to ecosystems. However, in addition to reducing the acceptance of phytoremediation, these factors can increase the operational cost due to maintenance, monitoring, and correct disposal of plant waste, according to the environmental regulations of each country (Maestri and Marmiroli 2011). These socioeconomic limitations formed concepts about the low adequacy of phytoremediation for certain types of contamination. On the other hand, the application of phytoremediation in underdeveloped countries has been suggested for remediation in landfills and potentially contaminated areas, reducing costs by 30 to 70% when compared to conventional techniques (Da and Uma 2012). Some results demonstrated a decrease in contamination, suggesting that this technology can be applied under various environmental conditions (Lamb et al. 2014; Stephenson and Black 2014). Therefore, despite being an innovative technology, phytoremediation is in the development phase; however, it is an economically viable technique for the recovery of contaminated areas, which can ensure biodiversity conservation, forming protected areas, such as legal reserves and permanent preservation areas (Ali et al. 2013).

Nonetheless, to choose the efficient decontamination technique, the analyses of the methodology for implementing dynamic decision models should be performed (Figure 7). There are several questions that should be discussed and answered during the decision-making stage of phytoremediation, including the phytotoxicity of any given site to the chosen plant species, the metal concentration and its bioavailability, the rate of metal uptake by roots, the rate of metal translocation via xylem to shoots, and the cellular tolerance of plants to metals and other abiotic stressors occurring on the site (Jaskulak et al. 2020; Santos et al. 2021; Valujeva et al. 2018). The use of dynamic decision models allows researchers, companies, and environmental agencies to understand phytoremediation methods. These models promote actions that contribute to the development of analytical tools for the choice of phytoremediation (Lousada and Pomim Valentim 2011). Such models simplify the variable visualization, support the identification of relationships between process phases, and serve as the basis for decision-making in the field (Jaskulak et al. 2020).

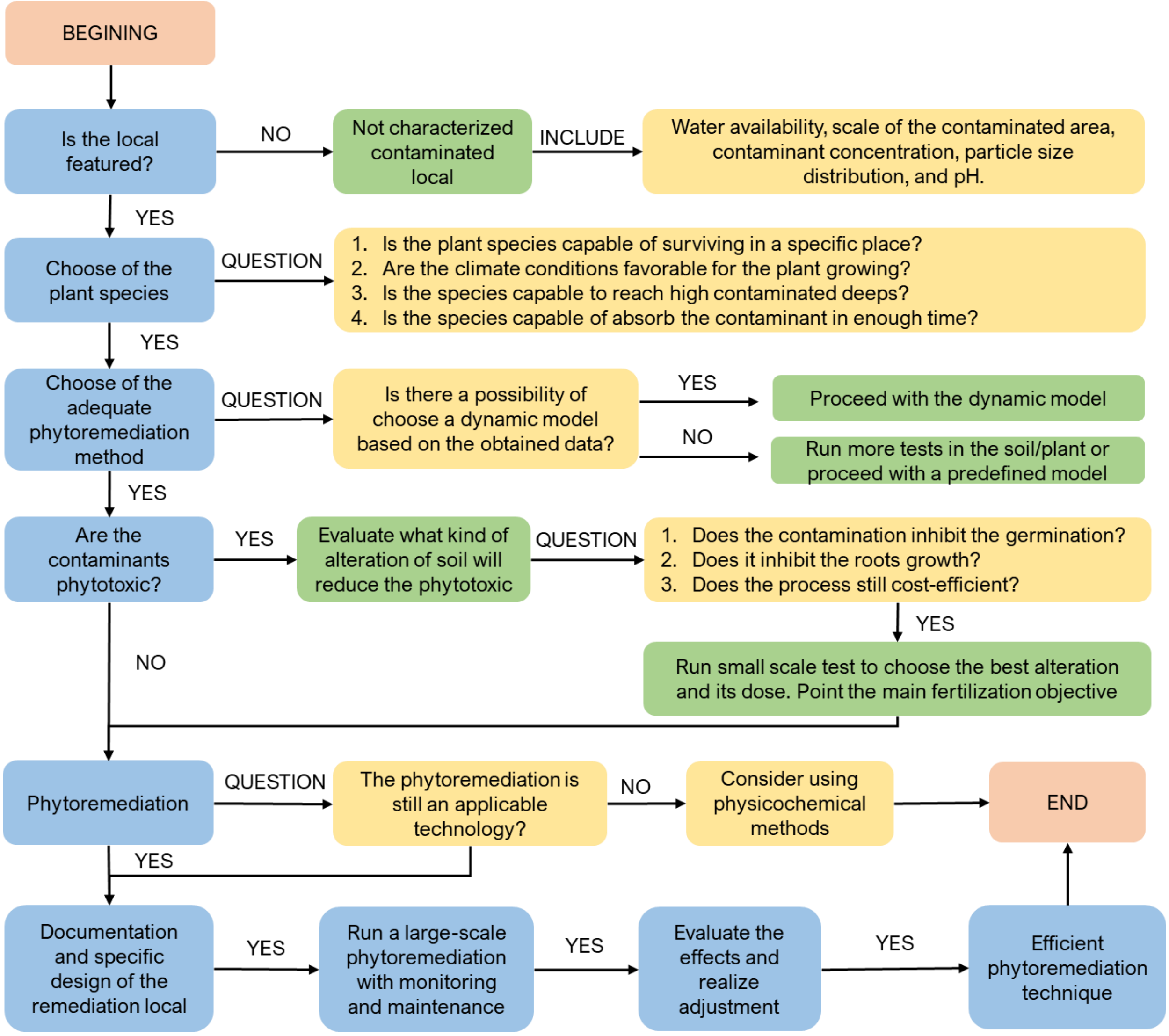

Figure 7. Decision-making scheme in phytoremediation (blue boxes indicate the stages of phytoremediation planning, green boxes indicate additional steps that provide assumptions for process efficiency, yellow boxes indicate issues that can help in planning).

Lewandowski et al. (2006) evaluated the costs of applying phytoremediation techniques and the expected benefits through risk, uncertainty, and sustainability aspects. Some of the economic criteria for the benefits to outweigh the costs are *i)* cost with soil analysis; *ii)* rehabilitation costs of each site; *iii)* tax costs; and *iv)* long-term costs (Dudai et al. 2018). These aspects support the decision-making of environmental protection agencies by techniques that reduce environmental risks at contaminated sites. Moreover, it provides important information to environmental researchers in the choice of remediation techniques, favoring the application of phytoremediation, involving mechanisms of capture, translocation, and accumulation of contaminants. Finally, the choice of the best remediation technique assists in ideal conditions for the subsequent use of these remedied areas (Maestri and Marmiroli 2011; Susarla et al. 2002).

Table 3 presents the economic, environmental, and social benefits of phytoremediation. Wan, Lei and Chen (2016) demonstrated the efficiency of phytoremediation compared to other techniques, reporting that phytoremediation can be applied for two years in soil contaminated by arsenic, cadmium, and lead. The results presented show that after the period of phytoremediation application, the concentration levels of contaminants were reduced to concentrations lower than the local standards stipulated. Regarding costs, the total value was 37.70 USD m^{-3}, falling below the values reported for conventional decontamination techniques. According to Saadia and Azka (2016), plants have selectivity in the absorption of contaminants. The species sunflower, turnip, and pea showed high bioaccumulation potentials for cadmium, chromium, and lead, respectively. In addition, Tavares, Oliveira, and Salgado (2013) showed that the species of sorghum and corn were the most effective in phytoextraction of heavy metals, decreasing the concentrations of copper, zinc, and chromium. This information demonstrates the applicability of phytoremediation as a promising alternative for the treatment of soils contaminated by heavy metals (Guarino et al. 2020; Zahoor et al. 2017).

Finally, several case studies were conducted to demonstrate the applicability of phytoremediation. A case study was conducted in a mining area in Hamedan Province in the west central region of Iran. *Euphorbia macroclada* and *Centaurea virgata* can be classified as hyperaccumulators of specific heavy metals, and they might potentially be used for the phytoremediation of contaminated soils (Lorestani et al. 2012). *Sida hermaphordita* depends on the bioavailable form of the metals in the soil. Additionally, fertilization can reduce heavy metal accumulation in plants. *Sida hermaphordita* can be recognized as a promising biomass source for energy recovery combined with phytoremediation technology (Pogrzeba et al. 2018). The aquatic macrophyte *Eleocharis acicularis* was examined for its ability to take up multiple heavy metals and its potential application for phytoremediation in an abandoned mining area in Hokkaido, Japan. *Eleocharis acicularis* shows great potential in the phytoremediation of mine tailings and drainage rich in heavy metals (Hoang Ha et al. 2009). Phytoremediation is the use of living plants to remove pollution from the environment, such as eliminating metal contaminants from the soil and restoring the ecological balance in a mining area (Ojuederie et al. 2022; Sarwar et al. 2017).

CONCLUSION

Phytoremediation may be considered an appropriate technique for the treatment of contaminated areas. Aspects such as the application site should be evaluated, highlighting the types of contamination in the soil and the selection of plant species, nutrients, and water levels. Phytoremediation presents low cost and fast remediation time, which can be beneficial for application when compared with conventional remediation methods. Although phytoremediation does not generate high financial returns, this technique ensures sustainability in environmental rehabilitation. The socioeconomic limitation of biological remediation is associated with the low adequacy for certain types of contamination; however, the applicability of phytoremediation can be a promising alternative for the treatment of soils contaminated by heavy metals.

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Table 3. Environmental and social benefits of phytoremediation.

Remediation mechanism	Soil treatment	Studied contaminants	Environmental benefits	Social benefits	Reference
Phytoextraction	Direct	Heavy metals (cadmium)	The method used can reach a Cadmium reduction rate of 40.5 to 46.1% in contaminated soil, further the improvement of the soil metabolic functions by increasing enzymatic activity.	Healthier soil for future use, besides the landscaping.	(Rakhshaee et al. 2009; Yu et al., 2020)
Phytotransformation	Direct	Organic contaminants (methylene)	Absorption and transformation of contaminants, besides the detox of organic pollutants in plants.	Landscaping, lakes, and rivers are free of contaminants.	(Al-Baldawi et al. 2018; Tariq and Ashraf 2016)
Phytovolatilization	Direct	Semimetal (arsenic)	The capability of fast recovery of contaminated soil and water with high concentrations of arsenic by volatilization.	It was possible to recover contaminated water with double the limit of contamination allowed in Europe, making it potable.	(Guarino et al. 2020)
Phytostabilization	Indirect	Heavy metals	Bioavailability reduction of pollutants by immobilization in root systems or biomass in soil rhizosphere.	Limits the leaching of contaminants and entrance in groundwater and further bioaccumulation, interfering in the food chain.	(Khalid et al. 2017)
Phytostimulation	Indirect	Heavy metals	The capability of remediating polluted soils with several heavy metals simultaneously, promoting plant growth and reducing metal toxicity.	Cleaning of lands, leaving the possibility of future utilization of the soil.	(Zahoor et al. 2017)

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