

Remediation Technologies for Polluted Sites: Review

Gemechu Fufa Arfasa (PhD, Candidate)
Faculty of Natural Resources and Environment, University for Development Studies.
P. O. Box 1882 Tamale, Ghana
Email: feragemechu@gmail.com

Prof. Samuel Jerry Cobbina (PhD)
West African Centre for Water, Irrigation and Sustainable Agriculture (WACWISA), University for Development Studies. P. O. Box TL 1882 Tamale, Ghana
Email: scobbina@uds.edu.gh

Justice Agyei Ampofo (PhD Candidate)
Faculty of Natural Resources and Environment, University for Development Studies.
P. O. Box 1882 Tamale, Ghana
Email: papajusty@gmail.com

Abstract
A polluted site can have serious consequences for human health, water supplies, ecosystems, and even building structures, which is why various safeguards have been put in place to address contamination issues. This systematic review will conduct a literature search on remediation technologies for polluted sites. Sources of information and search, eligibility and exclusion criteria, and a systematic searching strategy are used to retrieve articles related to remediation technologies for polluted sites. Heavy metal pollution in the soil is a worldwide problem that humanity is attempting to address. Heavy metal pollution can be found in varying degrees in the soils of all countries worldwide. Heavy metal-contaminated soil is cleaned using chemical, physical, and biological remediation technologies. Many methods have been developed over the last thirty years to remediate oil-contaminated soil. Biological techniques such as phytoremediation and land farming are used to remediate oil-contaminated soil. Groundwater poisoning by heavy metals, which can come from natural soil sources or man-made sources, is a major public health concern. Because contaminated groundwater serves as a source of drinking water for billions of people worldwide, remediation is a top priority. The best remediation technologies for containing groundwater water are pump and treatment, excavation method, permeable reactive barrier, air sparging, electrokinetic remediation, chemical oxidation, and bioremediation. The selection of remediation methods necessitates a thorough examination of technological effectiveness and economic environmental safety. Personal and trial examinations of remediation advancements continue. As a result, in future research, investigating the zero-valent iron powder restoration method in conjunction with other restoration methods to treat soil heavy metal pollution is critical to soil restoration and ecological restoration, revealing the main influencing factors of the restoration process as well as the promotion and implementation of this method.
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1. Introduction

The abatement of environmental pollution is one of the widespread challenges worldwide, proving as the largest danger to the human race and international biodiversity(Yadav et al., 2021). A polluted site can have serious consequences for human health, water supplies, eco-systems, and even building structures, which is why various safeguards have been put in place to address contamination issues.(Zhang et al.,2021). Site remediation deals with the elimination of pollution or contaminants from environmental media such as soil, groundwater, sediment, or surface water(Wan et al., 2020). Pollution enters the environment as a result of accidents, spills during transportation, leakage from waste disposal or storage sites, and industrial facilities. Pollution and the harmful effects of pollutants on global health are currently major sources of concern. Pollutant remediation, whether by physical, chemical, biological, or any combination of these methods, is the only way to remove them (Alka et al., 2021).

Disposal sites are a major source of pollution in the environment. The global increase in polluted sites has been identified as a serious concern (Yao et al., 2012). Because most remediation methods are site-specific, selecting the best one can be a difficult but critical step in restoring a contaminated site. As a result, proper selection, design, and adjustment of remediation technology operations based on the properties of contaminants and soils, as well as system performance, are critical to the effective treatment of a polluted site (Derakhshan Nejad et al., 2018). Remediation technologies are many and varied but can generally be categorized into ex-situ and in-situ methods(Singh et al., 2020). Ex-situ methods involve excavation of affected soils and subsequent treatment at the surface as well as extraction of contaminated groundwater and treatment at the surface. In-situ methods attempt to treat contamination without removing soils or groundwater. Various technologies for oil-contaminated soil/sediment remediation have been developed (Zhang et al., 2021). The present review focuses on review of Remediation technologies of polluted sites with the following objectives.

1.1. . Objectives

1.1.1. General objective

The general goal of this systematic review is to provide a survey of the literature on polluted site cleanup technologies.

1.1.2. Specific Objectives

- ✶ To provide an understanding of how soil and ground water remediation technologies are currently used.
- ✶ To characterize polluted site remediation technologies those are long-term.
- ✶ To describe how remediation efficiency is characterized in the literature and to map out potential efficiency indicators for future research.

2. Review Methodology

This section discusses the method used to retrieve articles related to remediation technologies of polluted sites

2.1. Sources of information and search

The electronic journal databases Web of Science (WoS) and Scopus were the primary sources of information. Both databases contain an Advanced Search feature that enables for a more thorough search to locate the relevant result. To combine the previously decided strategic concepts, the Boolean operators "AND" and "OR" were utilized. The strategic terms were derived from the concept and topic of the study's keyword and synonym. After the searches, the studies are loaded into the Mendeley desktop software suite for duplicate discovery and removal. Although these two electronic journal databases are not confined to Reviews Remediation technologies of contaminated areas, they do host top peer-reviewed articles with high impact factors in the subject of Pollution control technologies.

2.2. Eligibility and exclusion criteria

The type of literature, language, countries, and timeline are just a few of the eligibility and exclusion criteria that drive the journal database search. Only an online peer-reviewed article journal with empirical data was chosen. Despite the fact that some have empirical data, this study excludes valuable sources of information such as books, book chapters, book series, review articles, and conference proceedings, even if they are not necessarily peer-reviewed. This is because peer-reviewed journal publications are influenced by empirical studies that have gone through a rigorous research procedure to establish results and conclusions. (Shittu, 2019). As a result, the strategy is to make a concerted effort to address the vast amount of material available on the subject. To reduce misunderstandings and difficulties in translating the non-English article journal, the sole article published in English was considered next. The time span for this systematic review was set at six years (2014e2019). Recently published articles on remediation methods are sufficient to aid in a better understanding of the appropriate technologies to be used in dealing with a current pollution problem. These articles can be used by people involved in polluted site remediation technologies to practice the method being evaluated in current research. Finally, this paper will concentrate on polluted site remediation technologies. As a result, only articles on polluted site remediation technologies were considered.

2.3. Systematic searching strategy

The first step is to determine which keywords will be used in the search. The keywords were derived from previous research in order to identify synonyms and similar terms related to remediation technologies. The screening procedure comes next. This phase included records that had been examined and ruled out after duplicates had been removed (Sierra-Correa & Kintz, 2015). From the 593 items that were eligible for screening during this phase, 135 were removed. The final stage is eligibility, which shows which full-text publications were evaluated and which were not. The qualitative analysis was based on 39 papers discovered during the final stage of the systematic review process.

3. Technologies Used for Remediation of Polluted Site

3.1. Remediation Technology of Heavy Metal Contaminated Soil

Heavy metals such as lead, chromium, zinc, cadmium, and cooper may endanger human health and the environment due to their dissolubility and mobility. Heavy metals essentially become contaminants in soil environments because their rates of generation through man-made cycles are faster than natural cycles, they are transferred from mines to random environmental locations with a high potential for direct exposure, metal concentrations in discarded products are higher than those in the receiving environment, and the chemical form (species) of a metal found in the receiving environment is different (Derakhshan Nejad et al., 2018).

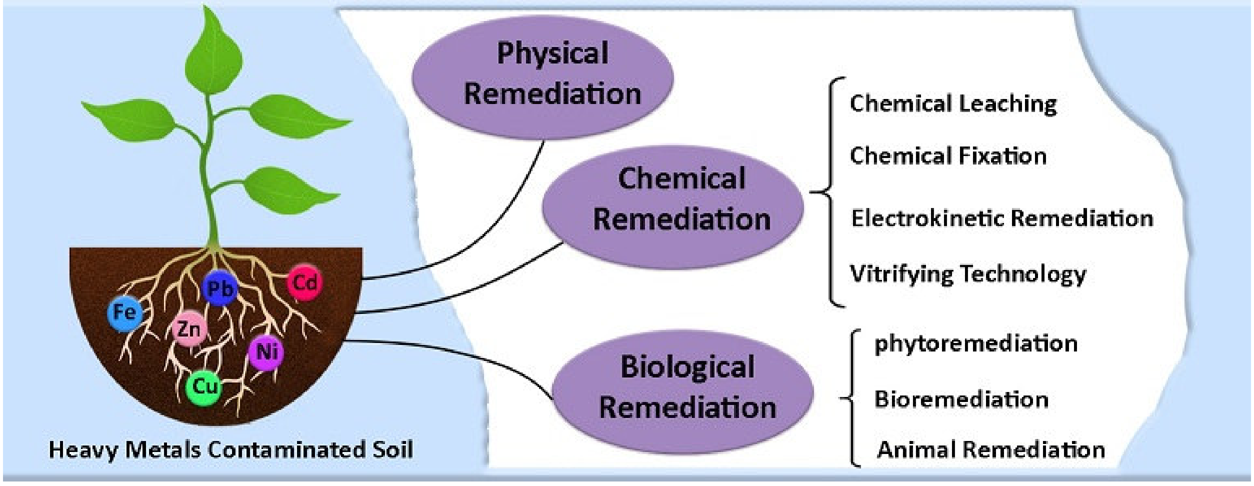

Figure 1: Description of main applicable technologies for contaminated soils heavy metals

Heavy metal pollution in the soil is a worldwide problem that humanity is attempting to address. Heavy metal pollution can be found in varying degrees in the soils of all countries worldwide. With the recent rapid development of the mining, metal smelting, coal chemical industry, and thermal power generation industries, a significant amount of heavy metals, waste liquids, and pollutants have been discharged into the environment. The direct release of waste liquids and the accumulation of wastes contribute significantly to soil heavy metal pollution. It is critical to expand research on heavy metal pollution control in soil because it poses a serious threat to people's health.(Tian et al., 2021). According to an examination of heavy metal polluted soil, the scope of heavy metal pollution is very broad, but heavy metal pollution control on the soil did not produce the expected results. Because of heavy metal pollution, the cadmium rice incident, for example, sparked a social uproar. Heavy metal poisons gradually accumulate in rice as it grows, leading to the poisoning.

3.1.1. Physical remediation

Soil replenishment and thermal desorption are the two basic components of physical soil remediation. In the soil replacement approach, contaminated soil is partially replaced with clean soil to reduce pollutant concentrations in the soil.(Sadia Qayyum et al., 2015). However, this method is expensive and only feasible in a small area. The thermal desorption method, on the other hand, heats the contaminated soil in order to volatilize the pollutant in the soil. These volatile metals are collected and removed from the soil using vacuum pressure. However, because it is time-consuming and expensive, this method has limited application in soil remediation (Singh Sidhu, 2016).

The physical remediation comprises of soil substitution strategy and warm desorption, too(Hashim et al., 2011). Soil substitution removes contaminated soil and replaces it with new soil, which is appropriate for a small degraded zone. Furthermore, the replaced soil should be dealt with potentially, or it will most likely cause subsequent contamination. Soil spading is the process of deeply burrowing contaminated soil and toxins into deep areas, with the goal of weakening and generally debasing the soil (Wan et al., 2020). New soil is created by dumping clean soil instead of polluted soil, completely from base to surface, or by blending to reduce poison fixation. A variety of advantageous circumstances, such as the need for a procedure, cell phones, and the ability to reuse the remediated soil, fully justify this innovation. A mercury collection and management company in the United States used this technology for restoration and business management (Chen et al., 2020).

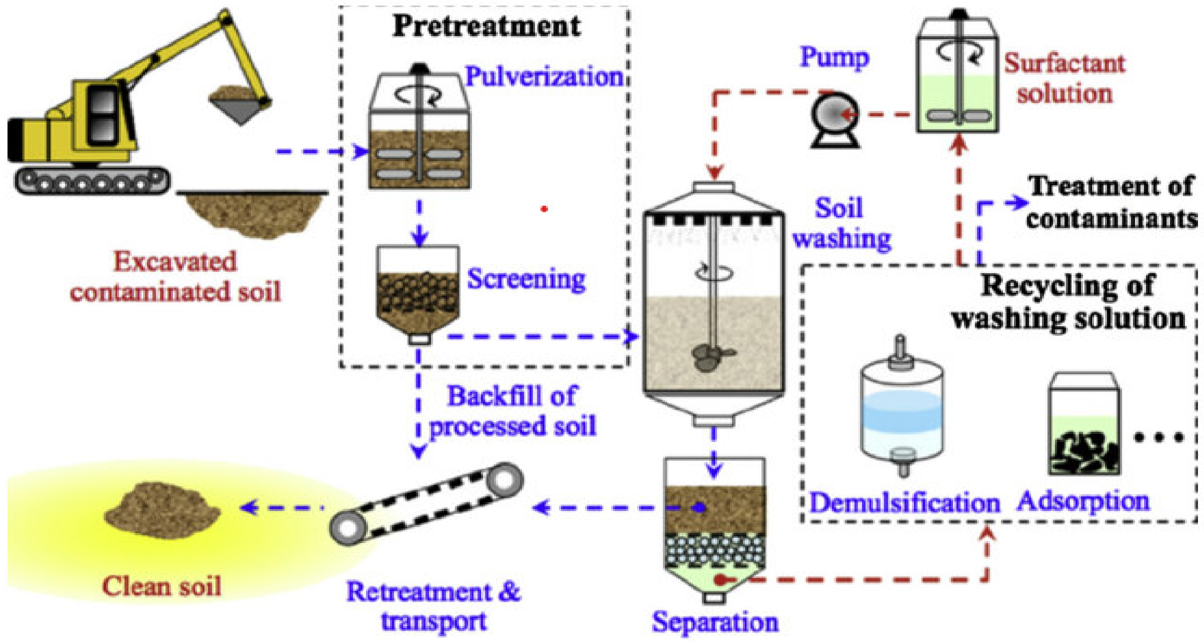

Figure 2: Schematic design of soil washing technology, Use of surfactants for the remediation of contaminated soils **(RoyChowdhury et al., 2018).**

3.1.2. Chemical remediation

Chemical remediation entails processes such as chemical leaching, chemical fixation, electrokinetic remediation, and vitrification, among others. The chemical leaching process entails washing contaminated soils with water, reagents, fluids, and gases, which aid in pollutant removal from the soil. The metals extracted using this method are recovered from the leachate using chelating agents, surfactants, and other substances. Chemical fixation involves the addition of reagents to contaminated soils that form insoluble bonds with heavy metals and reduce their mobility in the soils. Heavy metal-contaminated soil can be remedied using electrokinetic remediation, which involves applying high voltage to the soil to remove the metal. Finally, the vitrification process involves heating the soil to extremely high temperatures (1400-2000°C) in order for the pollutant to volatilize or decompose. However, because it is a costly, laborious, and complicated process, its use in removing contaminants from soil is limited (M D Yuniati, 2018).

3.1.2.1. Chemical leaching

This method involves washing of the contaminated soil with chemical reagents, gases or other fluids which help to leach the heavy metals (Pd, Zn, Hg etc.) from the polluted soils (Koul & Taak, 2018). Chemical leaching is washing the contaminated soil by using fresh water, reagents, and others fluids or gas that can leach the pollutant from the soil (Yao et al., 2012). Chemical leaching technology involves adding a leaching agent to contaminated soil in order to enhance the entrance of heavy metal compounds into the leaching solution and to wash away the heavy metals adsorbed in the soil as much as possible in order to achieve the goal of soil rehabilitation. The chemical leaching repair method is an advancement in chemical technology. This method is better suited to sand and gravel soils, and the effects of different leaching solutions on different heavy metals vary. Although chemical leaching is an excellent cleanup method, it has the potential to harm surface water. Simultaneously, certain soil nutrients reduce soil fertility, which has an effect on plant growth. Certain experts and scientists have demonstrated through practical implementations that combining chemical leaching technology with deep foundation reinforcement technology can produce better results (Tian et al., 2021).

3.1.2.2. Chemical fixation

Chemical fixation is the process of introducing chemicals or materials into polluted soil in order to stabilize pollutants by transforming them into a less hazardous state, thereby reducing their bioavailability, mobility, and ecological danger (Wuana and Okieimen 2011). Chemical fixation is the process of introducing reagents or materials into contaminated soil and combining them with heavy metals to form insoluble or barely movable, low toxic substances, reducing heavy metal migration to water, plants, and other environmental media and accomplishing soil remediation (Wan et al., 2020).

3.1.2.3. Electrokinetics remediation

Electrokinetic remediation is a novel remediation technique that entails applying voltage to both sides of the soil and then generating an electric field gradient (Yao et al., 2012). The physical method of electro-kinetic remediation is used to extract metals from damaged soil. Originally, this method was used to extract metals and organic substances from polluted soil. Tang and Ni (2002) Another soil remediation breakthrough is the application of voltage to different sides of the soil, followed by the sculpting of the electronic ground angle. Electrodynamic remediation entails placing electrodes in polluted soil and generating a weak electric field. Water or an external fluid in the soil void might be used as the medium. (Shi & Yang, 2021).

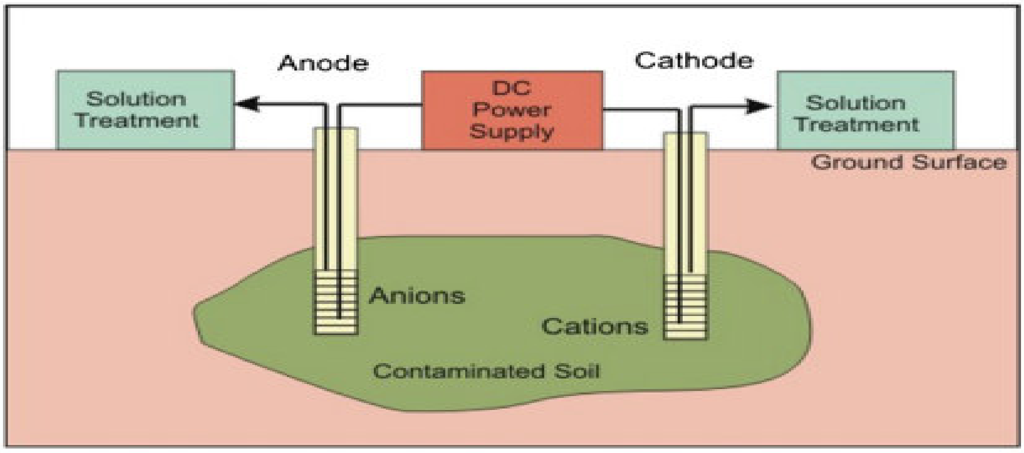

Figure 3: Electrokinetic treatment of soil contaminants **(García-Villacís et al., 2021).**

3.1.2.4. Vitrify technology

Heavy metal-contaminated soil is melted into glass using heat energy at high temperatures, and heavy metals are solidified into the glass body using the dense structure of the glass body. Another name for it is melting and solidification technology. For the first time, heavy metals in soil are effectively solidified using vitrification technology. Pollutant movement and transformation in the soil are reduced as a result. Despite the rapid pace, the engineering volume is massive, and the consumption cost is exorbitant. As a result, it's commonly used in heavy metal-contaminated soil that needs to be treated right away(Agarwal & Liu, 2015).

According to reports, the strength of vitreous is ten times that of concrete. Ex-situ remediation energy can be supplied by burning fossil fuels or directly heating electrodes and then transferring it via arc, plasma, and microwave. Electrodes placed in contaminated soil can deliver heat for in-situ treatment. To summarize, this method has a high level of effectiveness in removing heavy metals. However, melting it is difficult and requires a lot of energy, making it costly and limited in application (Derakhshan Nejad et al., 2018).

3.1.2.5. Immobilization

Immobilization is the removal of contamination from soil, which involves the removal and processing of a large amount of contaminated soil, which is expensive and time-consuming (Morillo & Villaverde, 2017). The immobilization process reduces metal solubility and, as a result, mobility in soil. To reduce metal toxicity through precipitation, sorption, and complexation, several organic and inorganic immobilizing amendments are used. Clay, organic composts, cement, minerals, phosphates, and zeolites are common immobilizing agents.(Zuzolo et al., 2021). Several studies have shown that other low-cost industrial residues, such as red mud and termitaria, can be used to immobilize heavy metals in soil. Immobilization procedures are frequently combined with soil capping technologies to encapsulate metals in a specific area. Binders are used for this purpose that are both inorganic (fly ash, bentonite, kaolinite, charcoal, Fe/Mn oxides, and calcium carbonate) and organic (bitumen (Hashim et al., 2011).

3.1.2.6. Extraction

The addition of chemical agents to bring the metals into the aqueous phase (by increasing metal solubility) in order to extract/remove the metals from the system is involved in this process. In this method, various types of inorganic eluents, chelating agents, and surfactants are commonly used. Because chelating agents can form bonds with various metals, they are widely used in physical, chemical, and biological remediation processes. Chemically induced metal extraction processes have been found to be more effective when combined with phytoremediation methods. (RoyChowdhury et al., 2018).

3.1.3. Biological remediation

Biological remediation is the use of living organisms to remove heavy metals from soil. It includes phytoremediation and microbial remediation for heavy metal removal from soils. Any of the five phytoremediation strategies can be used: phytoextraction, phytostabilization, rhizofilteration, phytovolatalization, and phytodegradation. Metals are transferred from the soil to aboveground plant parts during phytoextraction, resulting in a decrease in metal concentration in contaminated soils.(Al-Hashimi et al., 2021).

Phytostabilization, on the other hand, is the use of plants to reduce metal mobility and bioavailability in soil. Rhizofiltration is a technique for removing hazardous chemicals from contaminated water by using plant roots. The process by which plants absorb pollutants from the ground, move upward, and then expel them from the aerial portions is known as phytovolatalization. Phytodegradation, on the other hand, is the process of digesting contaminants in the soil using plant roots and related bacteria. The most common heavy metal removal techniques are phytoextraction and phytovolatalization, while phytostabilization and phytodegradation are commonly used for organic pollutants. Through the life metabolic activities of plants, animals, and microbes, bioremediation reduces the content of heavy metals in the soil or reduces the toxicity of heavy metals.(Tang & Ni, 2021).

3.1.3.1. Phytoremediation

Phytoremediation (phytoextraction, phytodegradation, phytostabilization and phytovolatilization) is a promising technology that exploits the inherent ability of plants to transform the pollutants through the conversion of usable sunlight energy into chemical energy (Yeh, 2021). One of the emerging technologies for heavy metal remediation is phytoremediation. Soil phytoremediation is thought to be a cost-effective and efficient method of removing Cd from polluted soil. However, in order to avoid secondary pollution, harvested biomass must be disposed of in a safe and cost-effective manner. Researchers discovered that incineration is frequently the most suggested choice when comparing general disposal methods of contaminated biomass, such as composting, compaction, incineration, ashing, pyrolysis, direct disposal, and liquid extraction.(Tang & Ni, 2021).

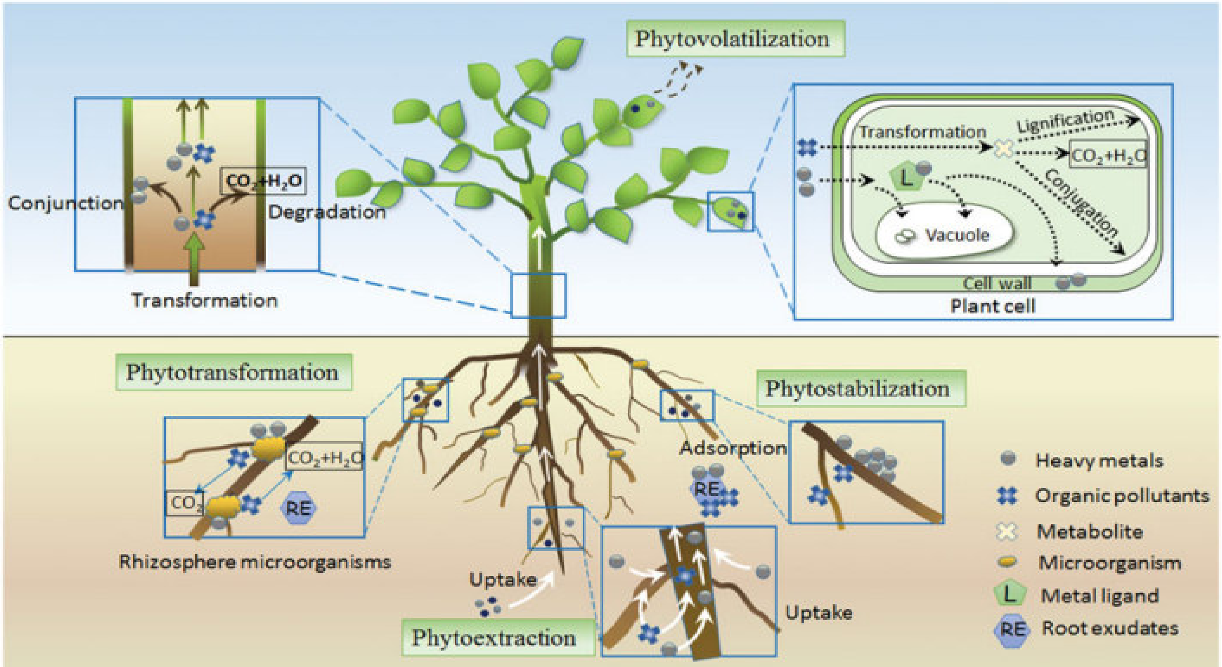

Figure 4: : The mechanisms of phytoremediation used for co-contaminated soil with heavy metals and organic pollutants (Do Nascimento et al., 2021).

Table 1: The impact of plant-microbe interactions on the efficacy of heavy metal and organic pollution remediation(Wan et al., 2020)

Plant species	Bacterium	Pollutants	Effect	References
C. odorata	Chromolaena odorata (L)	Cd, Ni, Zn and crude oil	The highest phytoremediation efficiency for Zn, Cd, and Ni was 63%, 62%, and 47%, respectively, with crude oil removal efficiency reaching up to 80%.	(Atagana, 2011)
Sedum alfredii	Pseudomonas sp. DDT-1	Cd, DDT and its metabolites DDE	Increased SA root biomass, the concentration of Cd and DDs reduced by 31.1% and 53.6%, respectively	(Boechat et al., 2020)
Sedum alfredii	Burkholderia cepacia	Cd, Zn, Cu, Pb, As and phenanthrene	Improved soil N and P nutrition, increased metal translocation factor, tolerance index, and phytoextraction efficiency, and eliminated up to 96.3% of phenanthrene.	(Ferrarini et al., 2021)

Plant species	Bacterium	Pollutants	Effect	References
Sedum alfredii	Bacillus subtilis, Flavobacterium and Pseudomonas sp	Cd and carbendazim	The microbial biomass, microbial diversities, and dehydrogenase activities were enhanced; increased the removal of Cd and carbendazim	(Zuzolo et al., 2021)
Brassica napus	Pantoea sp. FC 1	Cd and phenol	Promoted the growth of plant and bacteria and increased the efficiency of phenol dissipation and Cd accumulation	(Saeed et al., 2021)
Sedum alfredii and Festuca arundinaceae	BDE-degrader (Bacillus cereus strain JP12)	Cd, Pb, Zn and decabromodiphenyl ether (BDE-209	Improved plant growth and soil microbial activity, increased the BDE-209 dissipation and enhanced the metal phytoextraction	(Li et al., 2018)

3.1.3.2. Animal remediation

Animal remediation is based on the characterization of some lower animals that adsorb heavy metals, degrade them, migrate them, and thus remove and inhibit their toxicity. The earthworm-straw mulching combination treatment increased plant Cu concentration, with the quantity increased being lower than the earthworm treatment but higher than the straw mulching treatment (Burlakovs & Vircavs, 2012). Currently, hydrazine is the most commonly used method for repairing cadmium-contaminated soil. To improve contaminated soil, Alfalfa can loosen the soil, increase the decomposition of organic matter and waste residue in the soil, and improve the chemical composition and physical structure of the soil. On the other hand, it can be digested by the body surface or digestion, resulting in cadmium enrichment in the body and, to some extent, improving the soil environment. There are very few animals that can tolerate and enrich cadmium, so this method is rarely used (Han, 2019).

3.2. Remediation Technologies of Oil Contaminated Soil

Many methods have been advanced to remediate soil polluted with oil during the past thirty years(Mambwe et al., 2021).

3.2.1. Biological remediation techniques

Bioremediation, also known as biodegradation, is the process by which crude oil molecules are broken down by microorganisms via enzymatic processes, yielding carbon dioxide, biomass, and water-soluble chemicals (Atlas et al., 2015). Some environmental bacteria, such as yeast, fungi, mold, and algae, are capable of digesting crude oil molecules (Atlas et al., 2015). Bioremediation is a newer technology that has shown promise in treating hydrocarbon-contaminated soil. When compared to physical or chemical remediation, bioremediation is more commonly used due to its advantages of high efficacy, rapid degradation rate, and lack of secondary contamination. (Ahmad et al., 2020; Xu et al., 2018). Zhang et al. (2020b) remediated oil-contaminated soil using agricultural wastes through use of a bacterial consortium that was capable of decomposing oil components and the results showed a 68% decomposition of oil after 40 days using swine water among other additives confirming that certain strains of bacteria can be used in bioremediation.

According to a recent study, bacteria like Ochrobactrum sp., Stenotrophomonas maltophilia, and Pseudomonas aeruginosa can degrade crude oil (3 percent v/v) by more than 80% (Varjani et al., 2015), while another group of bacteria reported an 89 percent degradation of diesel-contaminated soil after 365 days (Varjani et al., 2015). (Szulc et al., 2014). Bioremediation, on the other hand, may not be a suitable remediation strategy because most hydrocarbons are hydrophobic and have low bioavailability (Zhu and Aitken, 2010). Biostimulation (Abed et al., 2015; Emami et al., 2014; Ezenne et al., 2014; Hamzah et al., 2014; Huang et al., 2014), bioventing (Amin et al., 2014; Thomé et al., 2014; Mosco and Zytner, 2017), and bioaugmentation (Amin et al., 2014). (Abdulsalam et al., 2011; Adlane et al., 2020; Roy et al., 2014; Singh et al., 2012) Bioremediation may be impractical at sites with high levels of hazardous chemicals such as cadmium, lead, and sodium chloride, which are toxic to most microorganisms (Speight, 2018).

3.2.2. Phytoremediation

Plant-assisted bioremediation, also known as phytoremediation, is a method of soil remediation that makes use of plants and their roots. Plant species include Centrosema brasilianum, Stylosanthes capitata, Calopogonium mucunoides, Brachiaria brizantha, and Cyperus aggregatus (Sadia Qayyum Et Al., 2015). Plant root enzymes aid in the decomposition process by chemically altering and decomposing toxic waste. Another low-cost method for cleaning up oil-affected soil is phytoremediation, or the use of vegetation to remediate contaminated soil in situ. According to, this method can be used to treat PAHs and petroleum hydrocarbons, among other things (Nedunuri et al., 2000). The treatment capitalizes on plants' ability to absorb, accumulate, and/or degrade readily available elements in soil and water environments. All the chemical, physical and biological activities that are induced by plants to assist and support the remedy of contaminated substrata all relate to phytoremediation. Fig. 5 shows some mechanisms involved in phytoremediation as illustrated by (Morillo & Villaverde, 2017).

The availability of organic materials such as root exudates and mucilage secretion by root caps, which are easily degraded and can thus improve the degradation of oil pollutants, is credited with the procedure's success (Merkl et al., 2005). Fertilizer can be added to provide additional nutrients to microorganisms and plants. When Festuca arundinacea and Festuca pratensis were used to degrade petroleum hydrocarbons, they removed 80- 84% of polyaromatic hydrocarbons and 64-72% of total petroleum hydrocarbons (Soleimani et al., 2010). Though this procedure is very inexpensive and is used to eliminate potential environmental pollution, it is time-consuming and can take five to seven years, making it unsuitable for long-term results (Chen et al., 2020).

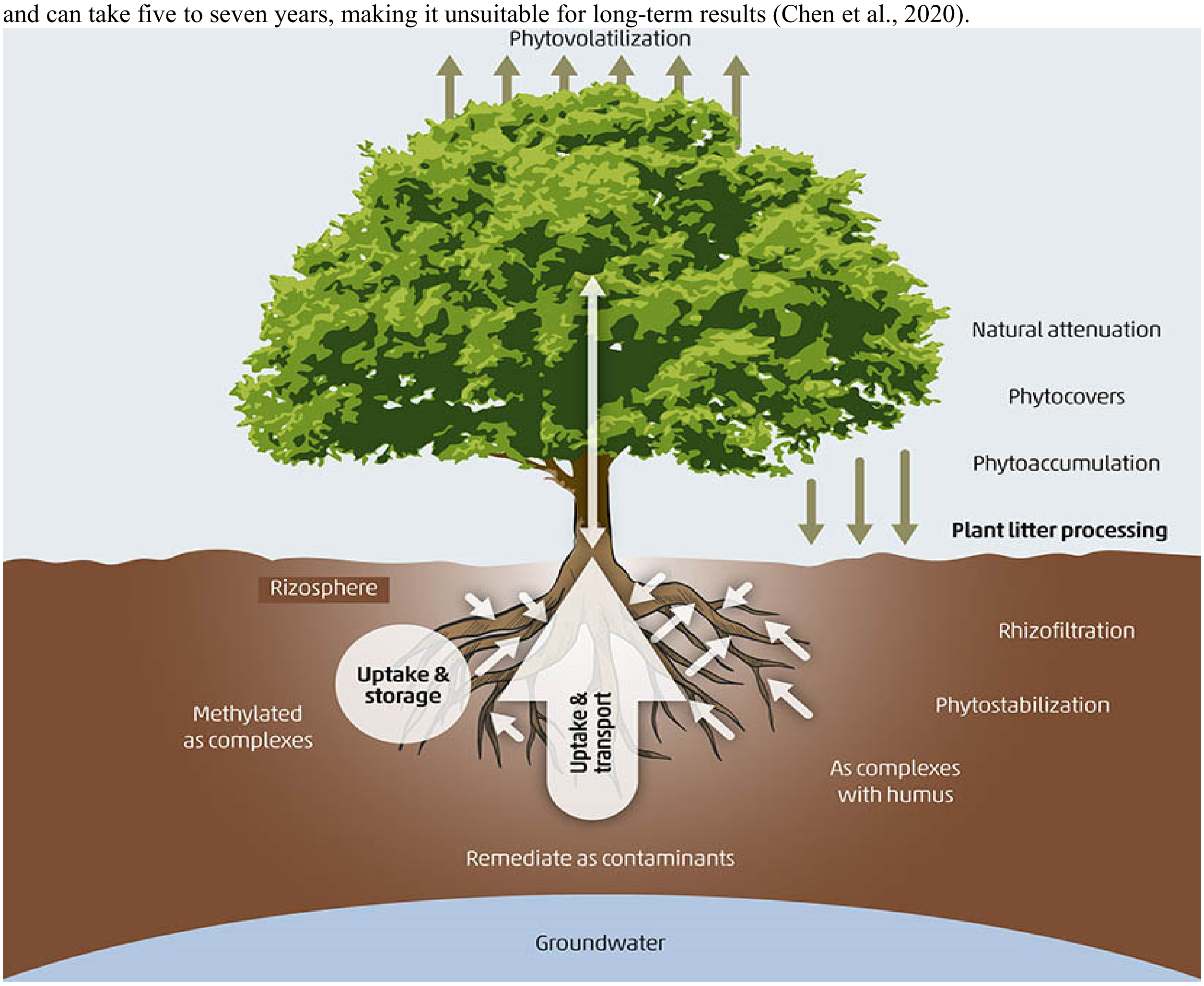

Figure 5: Phytoremediation mechanism (Mambwe et al., 2021).

Table 2: Types of phytoremediation technologies(Shi & Yang, 2021).

phytoremediation technologies	Technologies principle	Characteristics	Reference
Phytodegradation	By using the plant's metabolic mechanism or enzymes, degrade the ingested pollutants into less hazardous molecules.	Most suited for moderately hydrophobic organic chemicals	(Yadav et al., 2021)
Phytoextraction	Absorb organic matter from the soil into the plant body through plants that have an enrichment efect on pollutants	Depends on the bioavailability of pollutants	(Saeed et al., 2021)

phytoremediation technologies	Technologies principle	Characteristics	Reference
Phytostabilization	Reduce the mobility and bioavailability of pollutants through root adsorption or the formation of insoluble compounds in the root zone, preventing pollutants from leaching into ground water and the food chain.	Does not reduce the concentration of pollutants but reduces the contamination of nearby media/ area	(Boechat et al., 2020)
Phytostimulation	Plants release specifc root exudates (enzymes, organic acids, etc.) to enhance the growth and activity of microorganisms in the soil, accelerating the removal of pollutants	Cannot be done alone by the plant, always has close interaction between the microorganisms in rhizosphere	(Tian et al., 2021)
Phytovolatilization	Utilizes plant-mediated polutant uptake, then converts them to volatile compounds and releases these compounds into the atmosphere via metabolic and transpiration pull.	Does not completely remove the pollutants from the environment	(Al-Hashimi et al., 2021)
Rhizofltration	Adsorption or precipitation of pollutants by plant roots	Requires a full understanding of the contaminant speciation and interactions of all contaminants and nutrients	(Derakhshan Nejad et al., 2018)

3.2.3. Landfarming

Land farming is a process in which hydrocarbon-polluted soils are widely dispersed in an overlay nearly half a meter thick, nutrients are added, and the soils are occasionally mixed. Because of differences in location, climate, soil type, and temperature, land farms may have different treatment routines. Land farming has been successfully implemented in much warmer climates, whereas conflicting results have been reported in cold Antarctic and Arctic environments. In this remediation technique which is normally applied to petroleum hydrocarbons, the excavated oil-contaminated soils are firstly dispersed as a shallow layer ground surface where the intervention would be done followed by stimulation activity by microbes within the soil by aeration, the addition of nutrients, water and minerals (Khan et al., 2004).

Table 3: Processes for dealing with oil-contaminated soil that are often used biologically (Wan et al., 2020).

Method	Design and area of focus	Key Findings	Gaps/annotations	Reference
Bioremediation: Biological process	Contaminated soil treated with swine wastewater and wheat bran.	After 40 days a degradation efficiency of 68.27 ± 0.71% was obtained.	Use of pig waste to mitigate soil pollution is valuable. Process needs external microbial agents to facilitate the biodegradation process.	Zhang et al., 2020b; Sivakumar , 2015
Bioremediation: Biological process	Sawdust and the rice straw were used to degrade petroleum in the contaminated soil.	After 5 months, the removal percentages for TPHs were 23.9%, 45.2%, and 27.5%, respectively, while the removal percentages for PAHs were 66.3%, 30.3%, and 26.9% for the sawdust, rice straw, and control treatments. The use of sawdust and rice straw, respectively, increases the removal of PAHs and TPHs.	Removal of petroleum was not associated with the variety of the microbes. Not all microbes play a role in petroleum elimination.	Huang et al., 2019

Method	Design and area of focus	Key Findings	Gaps/annotations	Reference
Phytoremediation: Biological process	Hyparrhenia rufa, Sorghum arundinaceum, Oryza longistaminata and Tithonia diversifolia plant species were used.	TPHs were reduced after 120 days of phytoremediation combined with 5 gkg1 soil of manure. ii) There was no significant difference in TPH treatment between manure 5 gkg1 soil and manure 10	) Phytoremediation on its own was not ideal for successful bioremediation of the contaminated soil ii) No quantitative percent removal of oil was provided.	Ruley et al., 2020
Landfarming: Biological process	A combination of landfarming,phytoremediation and chemico-biological methods wasused.Targetcomponents were with (PAHs) and (TPHs).	i)The landfarming method was the best of the three remediation techniques used, with phytoremediation being the least effective. ii) 90% degradation of	Landfarming produced better results because of the combination of inorganic and organic fertilizers	Okonofua et al., 2020

3.3. Remediation Technologies of Groundwater Contaminated by Heavy Metal

Groundwater poisoning by heavy metals, which can come from natural soil sources or man-made sources, is a major public health concern. Because contaminated groundwater serves as a source of drinking water for billions of people worldwide, remediation is a top priority.(Hashim et al., 2011). The development of soil and groundwater remediation technologies is critical for the elimination of historically and currently contaminated sites because ongoing pollution degrades environmental quality, site operation possibilities, and land of full value use.(Burlakovs & Vircavs, 2012).

Groundwater contamination is becoming a serious issue because the contamination sources have not been effectively addressed (Garca-Villacs et al., 2021). Water resources have recently been impacted by organic and/or inorganic contaminants as a result of population growth and increased anthropogenic activity, soil leaching, and pollution. Water resource remediation has become a critical environmental concern due to its direct impact on many aspects of people's lives. Al-Hashimi and colleagues (2021).

4. Remediation Technologies of Petroleum Contaminated Soils

4.1.1. Sources of Petroleum Pollutants

Figure 7 depicts the main pathways through which petroleum pollutants enter the soil. Petroleum spills are a major source of hydrocarbon pollution in soil. The global leakage of natural petroleum is estimated to be 600,000 metric tons per year. According to estimates, petroleum contamination has contaminated 3.5 million sites across Europe. In China, approximately 4.8 million hectares of soil may have petroleum concentrations that exceed the acceptable limit. Different countries and regions use varying sampling and transportation methods, as well as different sources and levels of petroleum contamination. Furthermore, as a result of rainwater washing and leaching, pollutants are leached into the surrounding and deep soil in horizontal and vertical orientations, as well as into the groundwater system(Sui et al., 2021). Petroleum is a vital energy resource as well as a raw material in the chemical industry. Nonetheless, oil spills during exploration, transportation, and refining can cause some environmental issues with soil, groundwater, and air (Wan et al., 2020).

4.1.2. Chemical Remediation

Chemical oxidation has the ability to depose or preprocess soil pollutants quickly. Chemical oxidation remediation uses oxidants that can cause the chemical elimination of petroleum pollutants quickly and completely. Chemical oxidation turns hazardous impurities to non-hazardous, biodegradable products or less toxic compounds that are more stable, less mobile, or inert(Zhang et al., 2021). Oxidation, in waste remediation, refers to the movement of a contaminant to a more oxidized or more environmentally benign state. It involves the use of chemicals for the destruction of organic contaminant constituents. The chemical oxidants most commonly employed to date include peroxide, ozone, chlorine dioxide and permanganate. They can oxidize hazardous materials that are either organic or inorganic compounds.

4.1.3. Physical remediation

Physical remediation, which includes soil vapor extraction, flotation, ultra sonication, electro kinetics remediation, thermal desorption, and biochar adsorption, employs the physical properties of the contaminants or the contaminated medium to destroy, separate, or contain the contamination(De Voogt, 2015).

Ultrasonication aids contaminant desorption and increases the generation of powerful oxidants, hydroxyl radicals (OH•), which improve pollutant removal efficiency. Without the use of chemicals, ultrasonication can remove dangerous contaminants. Furthermore, on-the-spot heating and vigorous agitation improve heat and mass transfer processes. However, because of the higher energy usage for acoustic generating, it is the most expensive setup(Anderson, 2017).

4.1.4. Bioremediation

Bioremediation is the most cost-effective and environmentally friendly method of returning petroleum-contaminated soil and water to their natural state. The process of eliminating, decomposing, or changing pollutants into less hazardous or innocuous compounds is referred to as "remediation." It entails techniques that limit contaminants' mobility and migration, preventing them from spreading to uncontaminated areas; the contaminants' toxicity is unaffected, but the environmental harm they cause is reduced. M. D. Yuniati (2018).

Bioremediation is a cutting-edge technology for microorganism control. It degrades or converts hazardous organic pollutants such as CO2, CH4, H2O, and biomass to non-harmful chemicals such as CO2, CH4, H2O, and biomass. Hydrocarbons are naturally occurring energy-dense molecules. Hydrocarbons are degraded or used by a variety of creatures in nature. As a mitigation strategy, the use of a single indigenous microbe or a consortium takes advantage of living creatures' catalytic ability to accelerate pollutant degradation (Yao et al., 2012).

Table 4: Key technologies for soil remediation (Zhang et al., 2021)

Remediation technologies	Technologe principle	Characteristics
Physical–chemical remediation		
Vapor extraction	Drive air through the pores of the contaminated soil, thereby entraining VOCs to the extraction system, pumping to the ground, and then collecting and processing	Suitable for unsaturated areas, high permeability sites, and volatile organic pollutants.
Thermal desorption	During the heating process, the organic pollutants in the soil accelerate decomposition and volatilization, and the contaminated gas is extracted and collected from the soil via the suction system for processing.	Suitable for volatile organic matter and semi-volatile organic matter
Immobilization/stabilization	Immobilization: encapsulating soil pollutants in a solid material with complete structure; Stabilization: transfer pollutants into a state or form that is not soluble, transportable, or less toxic, reducing the bioavailability of pollutants	Contaminants cannot be fundamentally removed
Chemical redox	Add oxidant or reducing agent to contaminated soil, through oxidation or reduction, so that the pollutants in the soil into non-toxic or relatively less toxic substances	Not suitable for remediation of heavy metal contaminated soil
Soil washing	The eluent is injected into the contaminated soil, with the help of chemical/biochemical solvents that can promote the dissolution or migration of pollutants, transfer pollutants from the soil phase to the liquid phase. The wastewater from the elution system should be further treated	Not suitable for soil with a fne (clay/powder) content of more than 25%
Ecological remediation		
Phytoremediation	Use plants for extraction, rhizosphere fltration, volatilization, and fxation to remove, transform, and destroy pollutants in the soil, so that the polluted soil can restore its normal functions	Long processing time and slow results
Microorganism remediation	The method of transforming, degrading, and removing pollutants in the environment by using indigenous microorganisms in the natural environment or artifcially adding exogenous microorganisms	Suitable for integrated use with other methods

5. Conclusion and Recommendation

When selecting a remediation strategy, the effectiveness of technology, cost, and environmental safety must all be considered. The possibility remediation innovation development system includes green, natural, friendly organic remediation, consolidating remediation, and in-situ remediation. Soil contamination may have an impact on crop profitability as well as human health. Exploring the causes, fate, and occurrence of soil contamination, as well as the threats it poses to human health, has thus been a focus of research. Finally, using plants and algae to collect pollution can benefit human health by eliminating chemical approaches that are harmful to the environment, expensive, and require more energy.

The availability of trace elements was reduced in soils with Devonian clay addition, as demonstrated by cop per. In contrast, treating polluted soils with humic compounds may even increase trace element availability. Groundwater poisoning by heavy metals, which can come from natural soil sources or man-made sources, is a major public health concern. Because contaminated groundwater serves as a source of drinking water for billions of people worldwide, remediation is a top priority. The technologies covered in this invited literature are far from exhaustive, as new remediation technologies are constantly being developed to meet a wide range of demands. Readers interested in specific technologies will, however, find a comprehensive list of references to help them continue their research.

Further research into contaminated soil remediation technology should concentrate on green, environmentally friendly, biological remediation, as well as the combination of potential facilitating measures. Another important decision-making tool is the gap evaluation or comparison of different soil remediation technologies. More field experience is required to develop appropriate models that evaluate various aspects of remediation technology. In practical applications for contaminated sites, the screening approach has great potential to assist decision makers in selecting reasonable remediation options.

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