Review Article

Chemical Process to Removal Heavy Metals from Soil: A review

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Abstract

Over the past few decades, one of the most significant challenges that the globe has encountered is the pollution of soil with heavy metal ions. This contamination is a consequence of fast industrialization, and human irresponsibility. Heavy metal ions are extremely poisonous, even when present in low concentrations, and they are, by their very nature, non-biodegradable. It is their accumulation of biomaterials in the human body is responsible for several persistent and chronic disorders, including lung cancer, breakdown of the neurological system, respiratory issues, kidney impairment, and other conditions are examples. Moreover, aside from the increasing concentration of these metal ions in the soil, which is above the allowable limits, is what makes this situation problematic. The unsuitable soil for future use in agricultural production. Because of this, we need to keep an eye on the concentration of the presence of these metal ions in the soil and put in place some more advanced technology to eliminate them. As a result of the literature review, it was discovered that there are many methods for removing heavy metal ions from metal-contaminated soil. The elimination of these metals was the primary goal of these strategies so that the metal ions are changed into less harmful and toxic forms. The technique used depends on a number of factors, including the applicability of the method, the treatment mechanism used, the type and form of pollutants, the soil composition, the soil type, etc. For the purpose of this review paper, we conducted an in-depth investigation into the use of chemical techniques for the removal of heavy metals from contaminated soils and their application mechanism, in addition to mentioning their advantages and disadvantages.

Keywords: Soil, Contamination, Heavy metals, Chemical process

Introduction

Soil is a fundamental constituent. It covers a broad spectrum of services including food production, climate and water control, energy supply, and serves as the habitat for many living species [1]. Also, soil is a significant reservoir for many pollutants, such as heavy metals (HMs), classified as persistent contaminants due to their inability to undergo degradation or destruction. These elements occur naturally in the Earth's crust in various solid phase forms, as observed in soils, sediments, and dissolved minerals in water. Decreased concentrations of certain heavy metals, including iron (Fe^{+2}), copper (Cu^{+2}), cobalt (Co^{+2}), and zinc (Zn^{+2}), are crucial for metabolic functions [2]. Still, excessive levels are harmful to humans, plants, and microbes. Other HMs, including arsenic (As^{+2}), cadmium (Cd^{+2}), lead (Pb^{+2}), and mercury (Hg^{+2}), lack a recognized biological purpose and can cause severe toxic and carcinogenic effects, even at low levels. Consequently, they are considered primary metals of concern for public health [3]. Pollutants in soil affect humans, primary risks for people associated with soil contaminated with HMs [4-6].

Some soils naturally contain high amounts of HMs. Still, specific human activities contribute to the redistribution of HMs, resulting in significant environmental and human health hazards when concentration levels reach specified thresholds [7, 8]. Mining operations and mineral processing produce substantial quantities of metal-rich waste products, leading to significant expansions of mine boundaries: tailings and large-scale sludge dams (**Figure 1).** Airborne accumulation of particulate matter released during mining operations and industrial manufacturing; other significant sources of pollutants are motor vehicle usage [9, 10].

Another notable anthropogenic origin of HMs in agricultural soil pertains to specific agrarian techniques, such as the prolonged use of pesticides, fertilizers, or irrigation with wastewater (Figure 1). The uptake of metals by plants from soil is crucial for their proper growth;

nonetheless, uptake processes may include hazardous levels of vital and volatile compounds and non-essential heavy metals [11]. Transmission of contamination to plant aerial tissues can occur when heavy metals are directly deposited on the above-ground surface. Plants, as the initial component of the terrestrial food chain, should be closely monitored and targeted for reducing HMs concentration promptly [12]. Reducing the mineral components of the soil (total and accessible) and lowering the rate at which they are transferred to edible plant parts are the primary goals of treatments applied to soils polluted with HM. Additionally, these treatments attempt to increase the stability of the soil structure to prevent erosion [13, 14]. This is evident by the enormous number of scientific articles on this subject [15, 16]. Among the various remediation strategies that are currently accessible, those that are based on biological methods create large amounts of attention. This article provides information on remediation options for soils that heavy metals have contaminated.

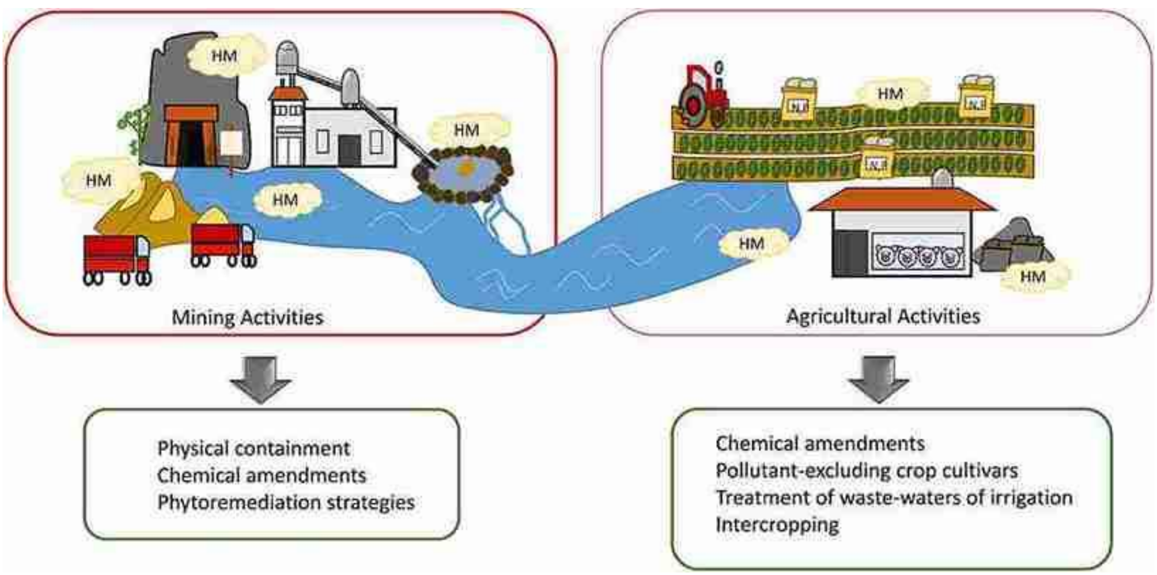

Figure1: Schematic representation anthropogenic sources of heavy metals accumulation in the environment [1].

2. Source of heavy metals in soil

Heavy metals originate in the environment from natural sources, including volcanic eruptions and forest fires, as well as the weathering and erosion of parent rock, which contribute to their presence in soil. Human sources encompass mining operations, vehicular exhaust emissions, and the overapplication of fertilizers, insecticides, and herbicides to augment agricultural yield. Agricultural practitioners polluted the soil with heavy metals like cadmium, copper, nickel, zinc, mercury, arsenic, and lead. Figure 2 illustrates the principal heavy metals accountable for soil contamination.

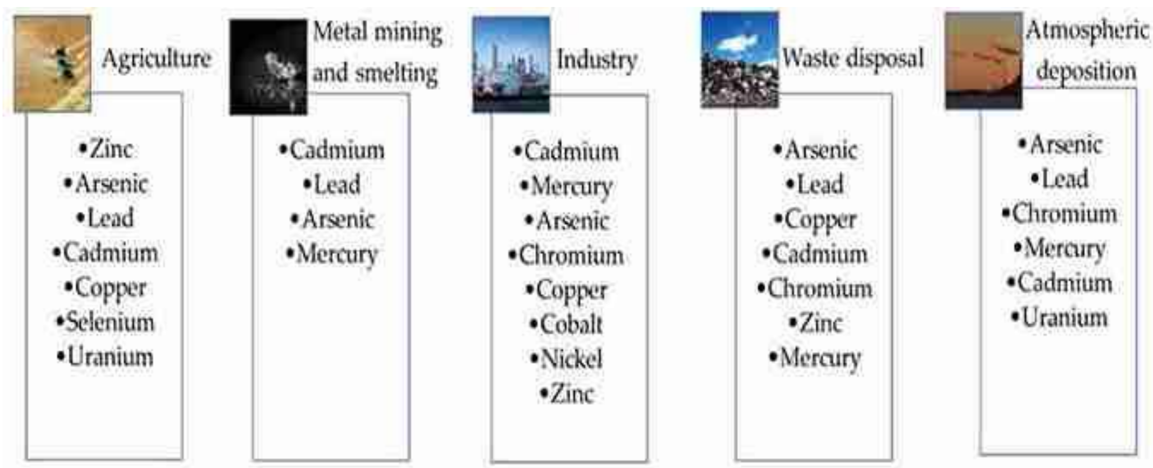

Figure 2: General source of HMs in environmentals [17]

2. Routes to exposure of HMs in soil

The three primary routes by which humans are exposed to soil materials are ingestion, breathing, and skin absorption or penetration. Deliberate ingestion, referred to as geophagy, or incidental ingestion, such as during hand-to-mouth contact (especially in youngsters) or when raw fruits or vegetables are eaten without sufficient washing. Especially prevalent among children is the ingestion of soil [18]. Which causes heavy elements to enter the human body and accumulate in living organs, which negatively affects human health.

2. Heavy metals and their effects on human health

There are many ways in which soil can negatively affect human health. It is through inhalation that heavy metals found in soil are absorbed by the human body. The widespread toxicity of metal ions is mostly due to the chemical interaction of these ions with cellular structural proteins, enzymes, and membrane systems. The organs most affected by particular metal toxicities are usually those that acquire the greatest amounts of the metal [19]. The degree of exposure to these elements and the concentrations of these elements in the soil both have a role in determining the impact that they have on human health. Insufficiencies in important elements, such as magnesium and iron, as well as toxicity caused by non-essential elements, such as lead and mercury, can both result in illness and, in some instances, death [20].

Several metals, including chromium and nickel, have been associated with the development of malignancies in human populations that have been exposed to them. Numerous studies have demonstrated that metals can induce both acute and chronic poisoning in people. Over time, these metal ions have made their way into the food chain, which has resulted in several ailments, including lung cancer and nervous system breakdown. Down, nausea, vomiting, cramping in the muscles, breathing issues, kidney impairment, and other symptoms [8]. Detailed information regarding the diseases, pesticides, and ions of metals are seen in **Figure 3.** In addition, **Table 1** provides further details regarding the properties, uses, and allowable limits in mg/L of various metal ions by WHO/UPEA **[12].**

Table 1: Permissible limits for heavy metals in soil according to World Health Organization [21]

HMs	Permissible limit of HMs (mg/L) in soil
Copper	1.3
Zinc	5
Cadmium	0.005
Chromium	0.1
Lead	0.005
Arsenic	0.05
Mercury	0.002
Nickel	0.05

Non-essential HMs

1. Cadmium (Cd)

Cadmium is a naturally occurring element that can be found in ores alongside zinc and lead. Although it is not considered a necessary metal, it is not known to have any useful roles in biology. Natural sources of cadmium come from volcanic fires in forests and wind-blown soil particles. Cadmium gradually accumulates in the human body when ingested through drinking water or inhaled, causing various adverse health consequences for the kidneys, liver and cardiovascular system. In the industrial sector, cadmium compounds are used in the production of plastic stabilizers, color pigments, solders, and a wide variety of rechargeable batteries [22].

2. Chromium (Cr)

Chrome is one of the elements that has been around for a longer time. Chrome can be studied in several forms, ranging from less than 0.1 $\mu g/m^3$ in the air to 0.1 mg/L in soils, with concentrations that have been fixed by the World Health Organization in the year 2000. There are a variety of applications for it, including electroplating, tanning factories, ferrochrome manufacture, and drying colour production [23]. The processes of metal plating, alloy manufacturing, metal welding, and metal forming are all included. The inhalation of chromium caused contamination through the consumption of contaminated food, polluted water, and contamination in the air. Then, several issues were encountered, including numerous instances of inflammation and ulceration, as well as difficulties in the pulmonary system, anemia, lesions in the stomach and small intestine, and attacks on the reproductive system in men are all symptoms that can lead to a decrease in the number of sperm [24].

3. Lead (Pb)

Lead is an element that occurs naturally and can be found in the environment, air, water, and soil. The contamination caused by lead that comes from nature is shallow; nonetheless, lead is an essential component in a wide variety of industries, including plastic, ceramics, paints, pesticides, and gasoline, amongst others [25]. The process by which lead is taken into the human body through inhalation both through the bloodstream and the skin. It can travel throughout the body via the blood, the soft tissues, and the bone. Causes damage, particularly in the kidneys it affects. The human body is susceptible to the carcinogenic and mutagenic effects of lead. Lesions associated with the reproductive system, immunological system, endocrine system, and gastrointestinal tract [26]

4. Nickel (Ni)

Nickel occurs in minimal quantities as a metal, identified in the 18th century, and is present in certain foods such as spinach. There are natural sources of nickel in the atmosphere, such as dust, volcanic emissions, and the weathering of terrestrial soils. Natural sources of aqueous nickel are derived from the cycles and compounds that occur in biological systems. Soils are formed. This material is used in the industrial sector for electroplating, electroforming, casting coins, producing jewellery, medical prostheses, and the fabrication of nickel-cadmium batteries. Automobile catalytic converters are another application [27].

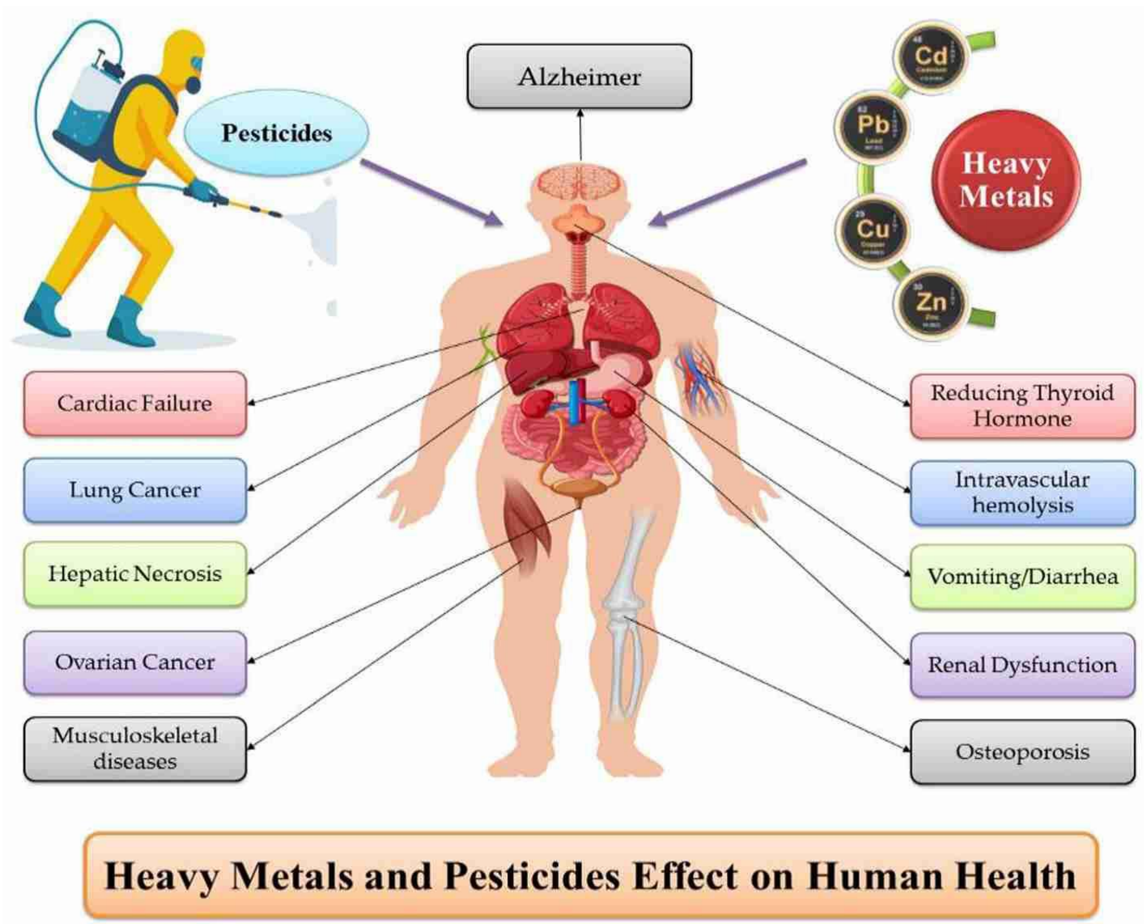

Figure 3. The influence that HMIs on the health of humans [11]

2. Various processes employed for the elimination of heavy metals (HMs) from soil samples contaminated

2.1 Chemical process

The remediation approach entails the utilization of an extraction fluid that contains chemical reagents. These reagents include surfactants, acids, bases, salts, and chelating agents. In order to transfer metals from soils to an aqueous medium [24]. **Figure 4,** show chemical process used to removal HMs from soil.

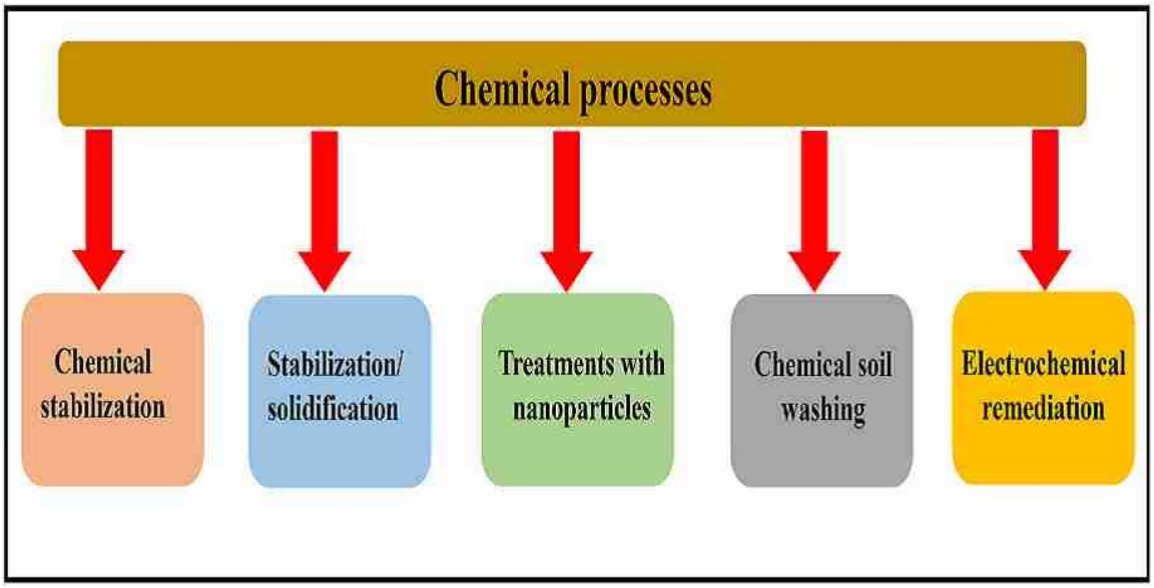

Figure 4: Chemical process used treatments soil from HMs [21]

2.2.1 Chemical Stabilization

This approach utilizes immobilized agents to reduce the mobility of heavy metal ions (HMs) in the soil. The main mechanism by which heavy metals are removed from soil is through the formation of complexes between chelating agents and heavy metal. These chelating agents have many functional groups like nitrogen, oxygen, sulfur, and phosphorus atoms for effective binding to metal ions. Study [28] investigated the oxidation of arsenite and the subsequent reduction of arsenite content in polluted soil by birnessite (MnO_2). Study [29] found that iron oxide decreased the levels of metals (Copper, lead, Chromium, and Zinc) and metalloids (Arsenic) in contaminated soil. Other study conducted by Jiang *et al*. (2011). To elimination nickel and copper from contaminated soil using chelating agents [30].

2.2.2 Stabilization/solidification

The basic principle of this technique is to stabilize pollutants in the soil by introducing chemical agents, such as asphalt and cement, into the heavy metal-polluted soil to create a solid, durable structure that prevents metal leaching, as shown in Figure 12. Initially, the stabilization process involves the use of a chelating agent to reduce the mobility of pollutants. In addition, solidification agents prevent the spread of pollutants for future integration into the ecosystem [31]. **Figure 5** Initially, the stabilization process involves using a chelating agent to decrease the mobility of the pollutants. Additionally, the solidifying agents serve to inhibit the diffusion of the contaminants. For future integration into the ecosystem. This procedure poses less risk to living and non-living systems as pollutants are retained within the treated region. In study conducted by Rudžionis *et al*. employed zeolite as binders to efficiently immobilize human metabolites of interest (HMIs) from solid waste [32]. In study adopted by [33], introduced a thiourea resin into the contaminated soil to effectively absorb and stabilize chromium and cadmium. The simplicity, suitability for stabilization, and non-toxicity of this resin to indigenous microorganisms were noted in comparison to other agents. In study, conducted by [34] employed cementing materials as a curing agent to stabilize and solidify Cd, Pb, and Cu removed from metal-contaminated soil .

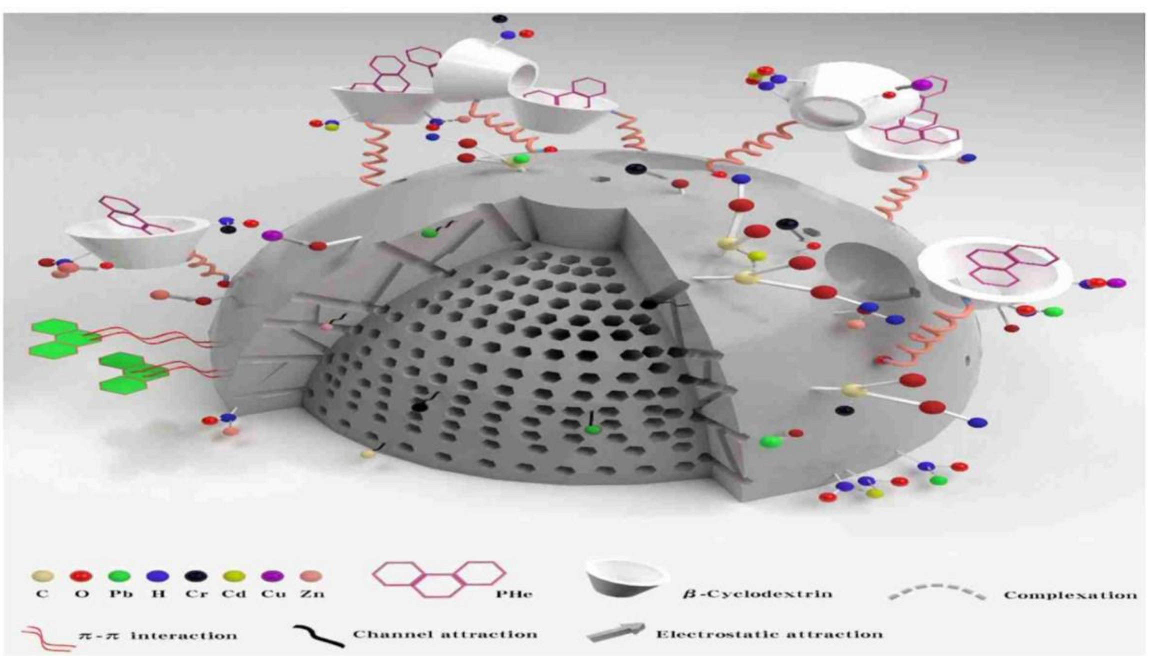

Figure 5: Stabilization of HMs pollution soil[35]

2.2.3 Treatment with nanoparticles

In recent years, nanoparticles have been extensively used in the remediation of metal-contaminated soil. Nanoparticles with a diameter below 100 nm can be used to sequester metals from metal-contaminated soil [36]. Several mechanisms, including redox reactions, precipitation, co-precipitation and adsorption were used to removal HMs from soil [37-39], as depicted in **Figure 6**.

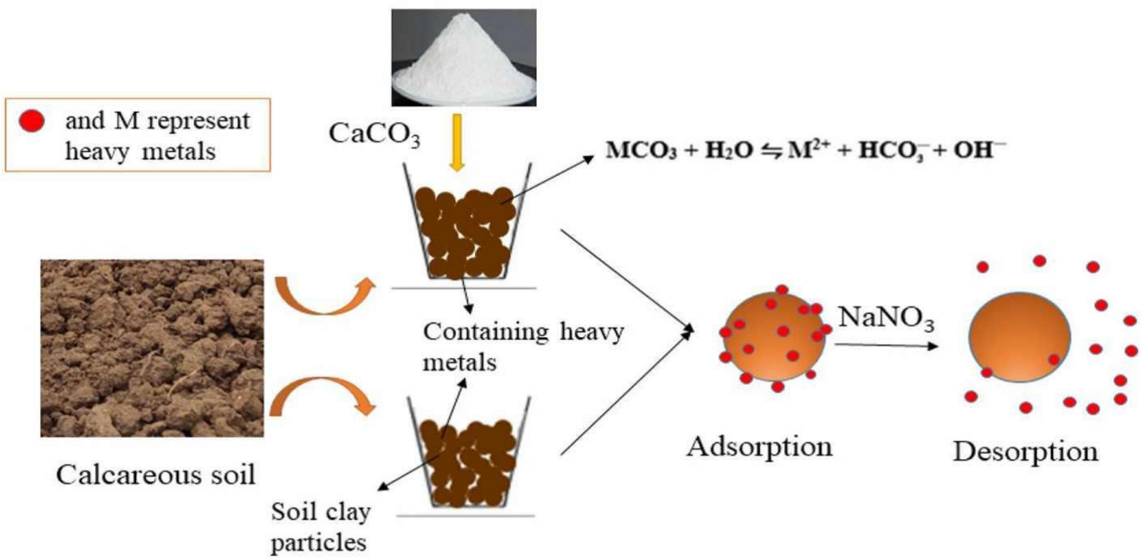

Figure 6: Adsorption HMs from pollution soil[40]

In study [41] synthesized silicon-NPs to enhance the absorption of Cd, Pb, Cu, and Zn from soil polluted with metals. The zeolite-based nanoparticles were synthesized by [42] to effectively eliminate cadmium, lead, and arsenic from soil contamination. Furthermore, study adopted by [43] produced Fe-NPs to remediate metals from locations contaminated by metals. Other study [44] synthesized Fe-NPs derived from maize straw. This study focuses on metal remediation from soil contamination. Furthermore, a study [45] observed that the newly synthesized zeolite-NPs were highly efficient in stabilizing cadmium, lead, and arsenic in agricultural soils contaminated with these metals. There are many applications for nanomaterials in removing heavy metals from soil as well as water, as shown in the **Figure 7.**

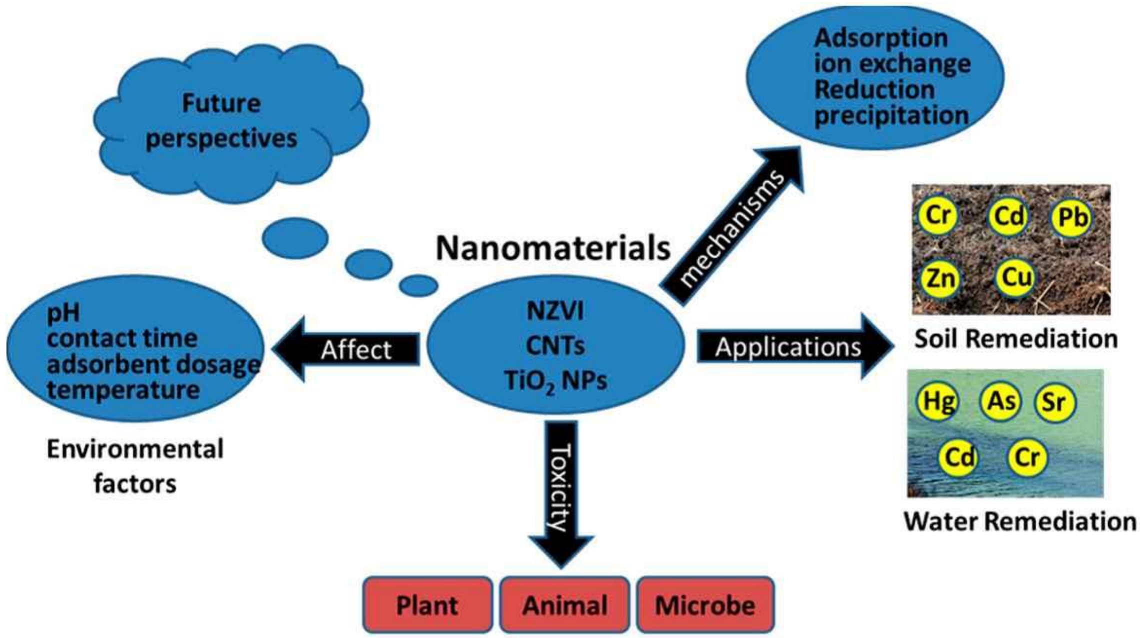

Figure 7: Application of NPs for removal HMs from soil and water [46]

2.2.4 Chemical soil washing

Soil washing is a combined chemical and physical techniques to eliminate HMs from polluted soil by washing the soil off-site with specially designed solutions (such as water, and organic acids). The basic working principle of this method is that heavy metals in the soil react with the washing solutions, resulting in the formation of solids in the form of sulfates or carbonates. At the end of the process, these materials can be removed by filtration [47]. As shown in **Figure 8**. In addition, uncontaminated soil can be repurposed as secondary fill material at the location. In study [48] employed this technique with a chelator to successfully immobilize heavy metals from polluted soil. However, this procedure fails to yield satisfactory findings due to the destabilized character of specific tightly bound fractions. Other study adopted by [49] investigated the synergistic impact of soil washing and in situ immobilization using lime, biochar, and carbon black, resulting in 36.5% and 73.6% reductions. This study reports the bioavailability of Cd, Cu, Pb, and Zn metals in soil to be 70.9% and 53.4%, respectively. Using polyacrylic acid and ethylenediamine, Feng *et al*. (2020) employed phosphonic acid effective in removing heavy metal inhibitors (HMIs) from the soil during the chemical washing process, thereby reducing the Comparative analysis of environmental hazards and toxicity of alternative agents [50].

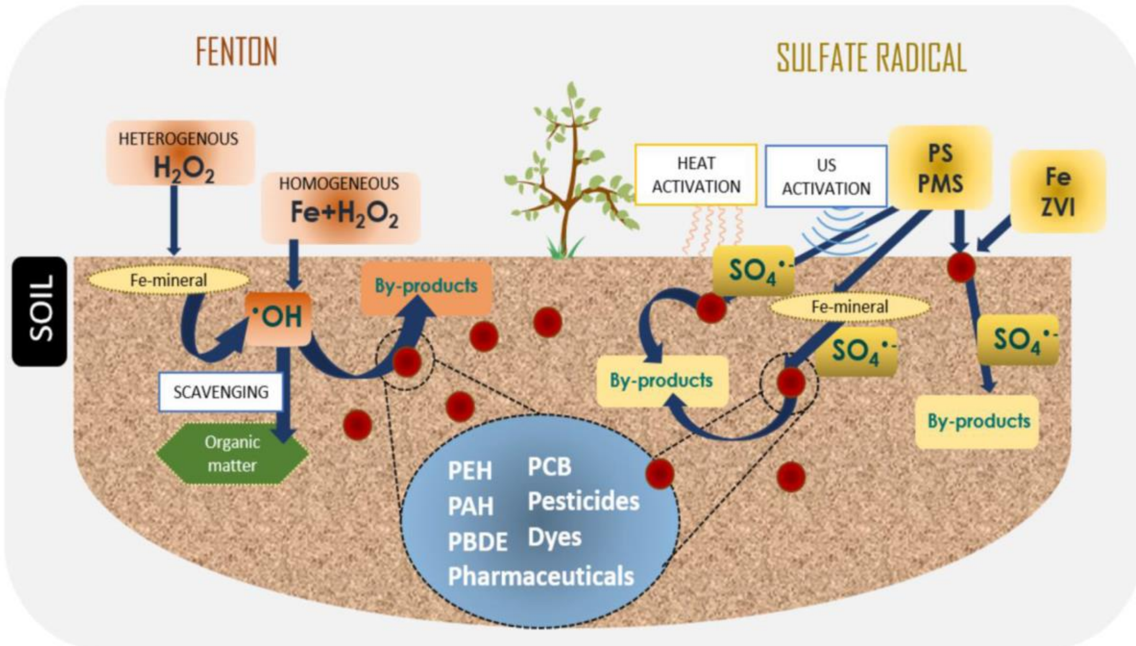

Figure 8: Show chemical soil washing for removal HMs [51].

2.2.5 E lectro-chemical remandation

The present remediation approach involves the application of a direct electric field to facilitate the migration of various metal ions pollutants towards the electrode with an opposite charge. Initial immersion of the electrodes in an electrolytic solution is followed by their insertion into the soil polluted with metal, as depicted in **Figure 9**. The generation of an electric field causes the migration of the HMI toward the electrodes with opposing charges [52]. The heavy metal ions (HMs) contaminants precipitate at the electrodes are addressed using several methods, including precipitation, electroplating, and sorption. Several parameters influence the efficacy of metal removal, including the characteristics of the metal impurities, the applied electric field, the conductivity of the electrolyte, and the electrode material [53]. Electro-migration transfers charged particles by applying a high-density electric current across a fluid sample. The Electric field voltage, electrolyte concentration, and force voltage determine the electro-migration process [53]. In study, Reddy and Cameselle (2009) used an electrokinetic approach to Recovery of metals from soil, sediment, and groundwater polluted with metals [52]. In study [54] employed carbonized food use of trash as an additional method of eliminating copper from soil contaminated. The study conducted by Cameselle and Pena *et al*. (2016) showed that citric acids effectively eliminate high amount of toxic HMs from soil contaminated. Optimizing the electroosmosis and electro-migration remediation processes [55]. In a study conducted by Sun *et al*. (2019), they were able to remove 87.60% of cadmium ions in contaminated soil, using solvent extraction by applying an electric field [33] . Other study by [56] investigated the synergistic impact of organic acids to removal HMs from soil contaminated, the results shown 50% copper and zinc. Metallic elements were extracted from polluted soil by using this process

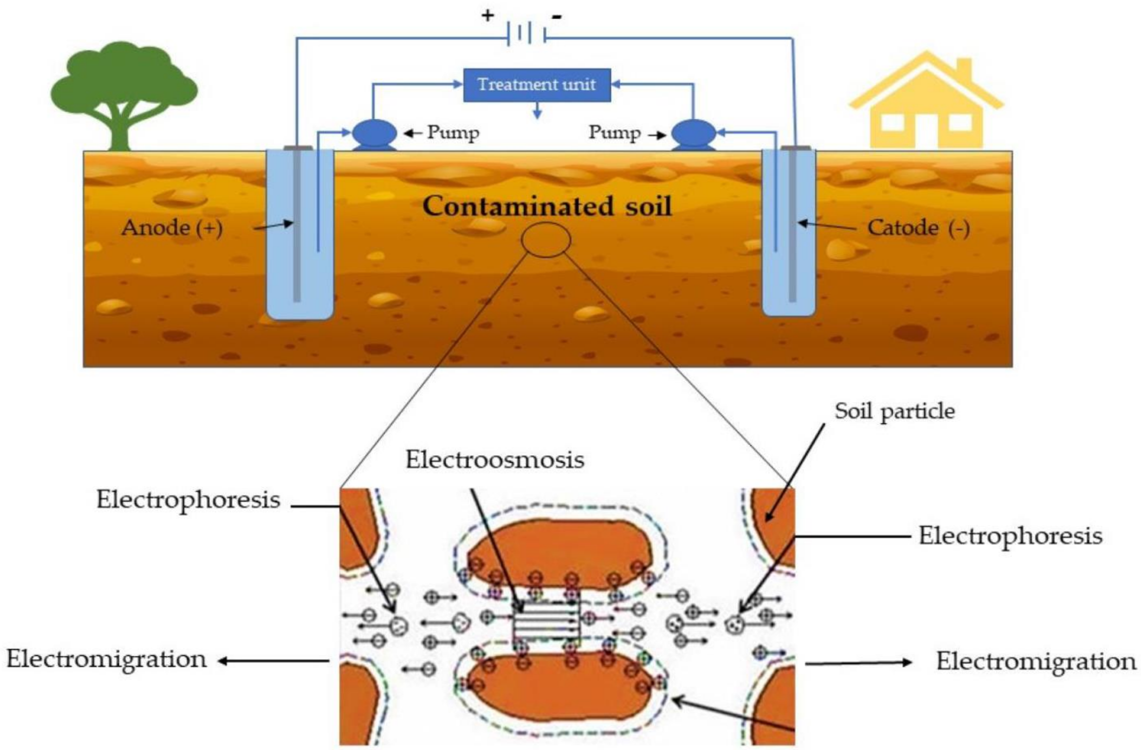

Figure 9: Show electro-chemical remandation to removal HMs [57]

Comparative benefits and drawbacks of chemical processes

Chemical removal techniques for heavy metals from soil are fast, efficient and widely used. Moreover, the continuous movement of the electric field in electrochemical treatment enhances the efficiency of this method for extracting metals from soils with low permeability. However, the presence of chemical agents changes the soil properties and generates secondary pollution that affects many aspects of biodiversity.

Conclusion

Heavy metals in soil pose a significant hazard to ecosystems. Despite ecosystems' notable tolerance to exogenous alterations, natural attenuation processes often occur at a sluggish pace. Consequently, the adoption of environmentally sustainable remediation solutions for soils contaminated with elevated levels of hazardous chemicals (especially heavy metals) is essential. Chemical procedures are among the most significant technologies employed for the extraction of heavy metals from soils.

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