Journal of
Advances in Environmental Health Research

Winter 2022. Volume 10. Number 1

Review Article

Lead Bioavailability in the Environment: Its Exposure and and Effects

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Citation Mousavi SM, Brodie G, Payghamzadeh K, Raiesi T, Srivastava AK. Lead Bioavailability in the Environment, Its Exposure, and Effects. Journal of Advances in Environmental Health Research. 2022; 10(1):1-14. http://dx.doi.org/10.32598/JAEHR.10.1.1256

http://dx.doi.org/10.32598/JAEHR.10.1.1256

Article info:
Received: 14 Aug 2021
Accepted: 25 Sep 2021
Publish: 01 Jan 2022

Keywords:
Lead, Bioavailability, Food chain, Public health

ABSTRACT

Many anthropogenic activities result in the accumulation of potentially toxic metals (e.g. lead, cadmium, chromium, nickel, arsenic, cobalt, and mercury) in the environment. Lead (Pb) is a very toxic and non-biodegradable element with no metabolic function in living creatures. It can be quickly taken up and transferred within plant tissues and then enter the food chain, causing phytotoxicity. Through different biochemical and enzymatic reactions, Pb can severely harm public health. After entering soil and sediments, Pb may mix with soil components and associate with them through different geochemical fractions, determining the final fate of Pb in terms of bioavailability and uptake by plants. Metal bioavailability in soils is mainly dependent on the soil and plant properties and interactions with other elements. Although there are numerous studies on the influence of heavy metals on public health, limited studies have considered the role of the soil-plant chain on the final fate of potentially toxic metals concerning public health. This article is a joint investigation between agricultural and medical sciences and reveals that the soil (as the base of agriculture) affects human health in various ways, and human health is linked to the health of the soil.

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1. Introduction

Anthropogenic activities, such as farming, manufacturing, and transporting, result in lead (Pb) accumulation in the environment [1]. If the density of an element is more than 5 g/cm^3, it is defined as heavy metal. According to Hasan et al. [2], among 90 natural elements, about 53 are classified as heavy elements with negligible biological activities. Under optimum physicochemical situations, 17 might be accessible by living organisms with significant roles in the environment [3]. Amidst these elements, nickel (Ni), copper (Cu), chromium (Cr), zinc (Zn), iron (Fe), cobalt (Co), and vanadium (Va) are not toxic at limited concentrations. Moreover, cadmium, aluminum, lead, mercury, arsenic, and silver, besides lacking nutritional roles, have some toxic effects on microorganisms. Lead (Pb) is readily absorbed and assimilated in plant tissues with several identified roles in metabolic pathways [4, 5]. The major features of lead include plasticity, malleability, ductility, and poor conductivity. Because of its malleability and relatively low melting point, this metal is easy to use. However, it is neither biodegradable nor desirable in production systems; increasing its concentration in the ecosystem is hazardous [5]. Knowledge and awareness of the problem are needed to limit the risk of lead exposure.

Chemical behavior and nature of lead (Pb)

Lead (Pb) is a metal in Group 4 and Period 6 in the periodic table. Its atomic number, atomic mass, density, melting point, and boiling point are respectively 82, 207.2, 11.4 g/cm^3, 327.4°C, and 1725°C. Pb is a naturally occurring, bluish-gray element commonly presented as a mixed mineral with other elements, and its normal concentration in the earth's crust varies from 10 to 30 mg/kg [6]. Typically, the concentration of Pb in surface soils changes from 10 to 67 mg/kg [7]. It also holds the fifth order in the industrial production of elements after Fe, Cu, Al, and Zn.

The common forms of Pb in the environment are ionic, Pb (II), oxides and hydroxides, and oxyanion complexes, of which Pb (II) and Pb-hydroxy complexes are the most stable forms. Pb (II) is the most usual and sensitive form of Pb. It forms mono-nuclear and poly-nuclear oxides and hydroxides [8]. The main stable/non-soluble Pb compounds are Pb (hydr) oxides, Pb carbonates (which form in pH >6), and Pb phosphates [9]. Lead sulfide (PbS), which forms under reducing conditions and in the presence of high levels of sulfide, is the most stable solid form of Pb in the soil. An unstable organo-lead (i.e., tetramethyl lead) may be produced because of microbial alkylation under anaerobic conditions [8]. Lead (II) compounds, such as Pb^{2+} SO_4^{2-}, are mainly ionic in nature, whereas Pb (IV) compounds, such as tetraethyl lead $Pb(C_2H_5)_4$, tend to be covalent. Some compounds of Pb (IV), e.g., PbO_2, are strong oxidants [10]. Numerous forms of Pb (II) and some of the Pb (IV) forms have no poisonous effect. The two most usual compounds are PbO_2 and $PbSO_4$.

In addition to the inorganic Pb compounds, there are several organo-lead compounds, for example, tetraethyl lead. The toxicity and ecological impacts of organo-lead complexes are very important due to the past extensive application of tetraethyllead as a gasoline improver. Even though up to 1000 organo-Pb complexes have been produced, their commercial and toxicological concern is mainly restricted to the alkyl Pb complexes and their salts [10].

Main sources of the lead entrance to the environment

The unrestricted developmental activities conducted throughout the past years have increased environmental contamination. Nowadays, the increasing processing and use of Pb is a critical problem of ecosystem contamination. Usually, the primary sources of Pb emissions are from ore, processing of metals, and leaded aviation gasoline (Figure 1). The greatest levels of airborne lead happen near to lead smelters. Other sources are the manufacturing of batteries, coal burning, typecasting, and older houses and buildings. Mining and smelting activities are the other major exposure pathways of lead's entrance into the environment [1, 11]. Farming practices, for example, spraying of pesticide and organic fertilizers as well as soil irrigation with wastewater, are also pathways for Pb release to the soil and water [12-14].

Lead stress in plants

Soil pollution with heavy metals not only affects soil microorganisms but also plant growth and development. The soil and atmosphere are the main pathways to pollutants' penetration into plant systems. Among them, Pb is a common pollutant toxic to living cells. Lead has distinct effects on plant construction; consequently, it may threaten human health.

Lead disturbs photosynthesis, decreases nutrient bioavailability, and unbalances water absorption and enzymatic functions [15]. Such abnormalities disturb normal physiological and biological pathways in plants. Pb at high concentration induces various symptoms in plants,

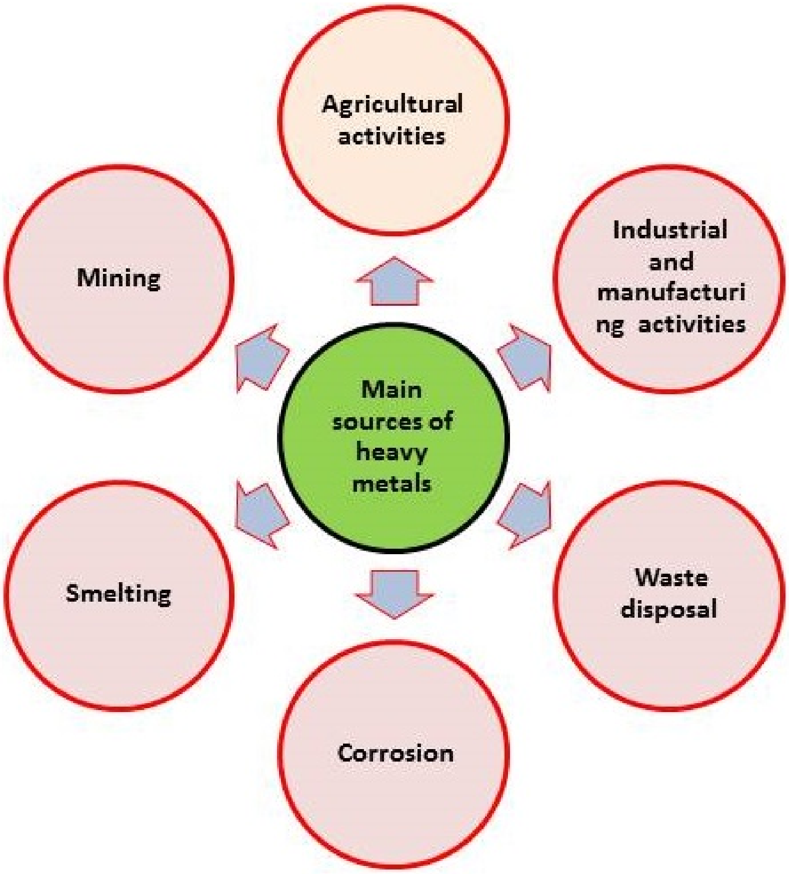

Figure 1. Main sources of heavy metals in the environment

including growth impediment, disturbed photosynthetic machinery, phytotoxicity of cell membranes, and other metabolic changes due to various cellular interactions. Pb modifies cell membrane, reacting with sulfhydryl bands as well as reacting with -P groups to convert adenosine diphosphate to adenosine triphosphate [16]. Damage to roots results in poor water and nutrient absorption because of long-term Pb exposure. Also, lipid membrane compositions and protein activities change, leading to plant shoot systems suffering from severe water and mineral nutrient deficiencies [17, 18].

As enzymes are the main target of various toxic metals, long-term exposure to Pb in the soil negatively influences both soil and plant enzymatic activities [19]. For example, it invigorates the formation of free radicals and reactive oxygen species [5], represses α-amino levulinate dehydrogenase, which is a main chlorophyll biosynthesis enzyme and suppresses the reductive pentose pathway-related enzymes and ATP synthetase/ATPase. In homogenate spinach leaves, the activity of rubisco was prevented by Pb nitrate at a concentration of 5 µM. During the treatment of isolated plants with Pb, organelles such as mitochondria and chloroplast were affected, indicating that Pb disrupts the electron transport systems [20], disconnects oxidative phosphorylation [21], and changes respiration [17]. Moreover, oxidoreductase enzyme activities (for example, chloramphenicol acetyltransferase-catalase), which are involved in the disintegration of hydrogen peroxide into its component (molecular oxygen and water), were increased at lower Pb concentrations; meanwhile, its activity decreased at higher Pb densities. At higher Pb concentrations, catalase spryness dwindled via reactive oxygen species involvement in its degradation or misassembling of subunits by the interaction of the enzyme sulfhydryl group [22]. Table 1 presents some acute effects of Pb toxicity on the growth of plants [4, 5, 17, 22, 23, 24].

Effects of lead on soil

Anthropogenically derived Pb is mainly found in the top layer of soil, and its concentration gradually decreases at lower depths. Lead may exist in soil constituents as a free ion, as a fraction of inorganic components (such as Cl^-, $-CO_3^{2-}$, SO_4^{2-} and HCO_3), as organic ligands (for example, humic acids, amino acids, and fulvic acids). Pb can integrate onto the soil particle surfaces [25]. Pb binds to soil constituents strongly; therefore, it is mostly

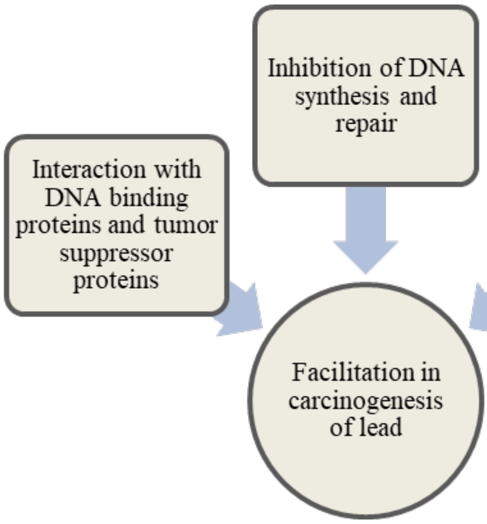

Figure 2. The facilitative roles of lead in carcinogenesis

insoluble, and thereby a small amount of Pb is available for uptake by plants [26]. However, many biogeochemical and physicochemical conditions influence Pb availability, solubility, mobility, and types [26].

Effects of lead on humans

Heavy metals such as Pb can enter the environment and human bodies differently. Pb can enter humans by contaminated food and water or by ingestion and inhalation of atmospheric particles. Ingestion of Pb in the delicate particulate matter has a high carcinogenic risk [27]. Exposure to Pb for a long period may cause memory deterioration, prolonged reaction time, and reduced understanding ability in people [28]. Studies on kidney and brain tumors in animal models have indicated that Pb acetate and Pb phosphate can be potentially carcinogenic. Exposure to environmental Pb also increases brain cancer risk [29]. Cancer researchers have categorized Pb as a potential carcinogen (group 2B) and its inorganic complexes as possible carcinogens in humans (group 2A) [28]. Lead exposure increases the risk of brain cancer by passing the blood-brain barrier, causing enhanced Pb concentration in brain tissue [6]. Increased blood pressure, muscle and joint pain, memory and concentration difficulties, mood disorders, headaches, abdominal pain, reduced sperm count, miscarriages, or stillbirth in pregnant women are other toxic effects of Pb on human health. Figure 2 shows how lead facilitates carcinogenesis.

Factors affecting availability and bioavailability of lead in soil

Heavy metal availability and bioavailability are determined by complex interacting reactions, including adsorption/desorption, complexation/dissociation, precipitation/dissolution, or very slow diffusion into the interior of clay minerals and oxides [30]. These reactions are, in turn, affected by soil's physical and chemical properties, such as the total concentration of metals, acidity, redox status, organic carbon content, clay minerals percent, oxides content, and the exposure time with the soil matrix. These reactions are considerably metal-specific due to the difference in chemical behavior and nature of heavy metals [1, 11, 31]. Based on Gray et al. [32], the total concentration of metal is the most vital parameter influencing the solubility concentrations and availability of metals, whereas soil acidity, total carbon content, and Fe and Al oxides present variable levels of importance. Soil pH is an essential factor in heavy metals mobility and availability in soil. Toxic elements, showing a considerable degree of specific adsorption, are usually considered as being slightly bioavailable [33]. In high acidity conditions, trace metals are mainly non-specifically absorbed onto the binding positions of ion exchange on clay minerals and oxides by means of electrostatic bonds, which are related to the exchangeable form of elements and regarded as being readily bioavailable [33]. Therefore, trace metals are more mobile and (environmentally) bioavailable in high acidity than moderately acidic to slightly alkaline conditions.

Soil organic carbon content, as an important soil quality factor, can change the adsorption and or solubility of elemental ions depending on the soil acidity and the organic matter type. The organic acids in the dissolved organic matter have the role of a chelating agent and increase the availability of trace elements [34]. However, some reports state that organic chelates do not increase the mobility and bioavailability of metals [1, 31]. One

Table 1. Some important effects of Pb toxicity on growth of plants [4, 5, 17, 22-24]

Variables	+/-	Growth of Plants
Root	+	Root decay
		Root darkling
		Becoming bent, swollen, and stubby
	-	Biomass
		Growth and elongation
		Respiration
		Primary and secondary roots formation
		Secondary root number per root length unit
Shoot	+	Fragile leaves with bluish-red abaxial surfaces
		Cell death
		Lipid damage
		Oxidative stress
		Disordering deactivation of enzymes
	-	Biomass
		Protein content
		Photosynthesis
Grain	+	-
	-	Yield
		Protein content and nutritional values

”+” and “−” signs are positive and negative effects, respectively.

reason for reducing the metals bioavailability by organic ligands may be the direct adsorption of ligands or ligand-metal combinations by the soil surface functional groups. There is a correlation between the role of soil organic matter on metals’ bioavailability and soil pH. Gray and McLaren reported that soluble/mobile Pb was directly correlated with soil organic matter percentage [32].

Interrelationship of lead with other elements

Plant species that grow on Pb polluted soils often absorb Pb, causing phytotoxicity. Lead toxicity affects root dynamics, decreasing water and nutrients (for example, Zn, P, Mn, Mg, Fe, and Ca) intake and their transport by blocking or binding to ion carriers, making them unattainable for roots and shoots. Consequently, many physicochemical processes, especially photosynthesis, were dramatically interfered with [35]. Because of its accumulative nature and strong relationships with Zn in plants and soil, it is suggested that each of these metals can translocate from roots to shoots separately or simultaneously and accumulate in different plant organs through uncertain processes [36]. Furthermore, it is reported that toxic metals have significant antagonistic interrelationships with micro-macro nutrients, and mainly Pb changes the Pb/Zn ratio with Zn decreasing [37]. In many plant species, e.g. *Thymus serpyllum* L.; *Senecio sylvaticus* L.; *Dianthus carthusianorum* L.; *Rorippa sylvestris* L.; *Silene vulgaris* L. and *Senecio aquaticus* L., the antagonistic effects of Pb and Zn were observed in stems and flowers at lower Zn concentrations (100-180 µg/g) and roots at medium Zn concentrations (200-600 µg/g) as well as in leaves at higher Zn concentrations (300-800 µg/g) [36].

Table 2. Lead (Pb) concentration (mg/kg) in soil from different countries

Concentration	Region	Site Sampling	Ref.
21.26-141.72	Taihu region, East China	Agricultural soils	[45]
51.36-642.54	Nain County, Iran	Agricultural soils	[46]
6.32-7.74	Punjab, China	Agricultural soils	[40]
Summer: 0.917-131.1 Winter: 118.8-349.8	Yuhang County, China	Agricultural soils	[47]
Northern: 1.6-52 Southern: 2.1-1309	Europe	Agricultural soils	[48]
0.8-929	Poland	Agricultural soils	[49]
4.16-21.60	North India	Agricultural soils	[50]
10.5 - 62.5	Babol City, Iran	Urban and rural places	[51]
116-1220	Kaduna State, Nigeria	Tropical grassland, urban	[44]
0.99-112	Pakistan	Suburban soils	[52]
22 to 830	New Jersey (NJ), USA	Farmed urban soils	[53]
175–7935	New Jersey (NJ), USA	Residential soils	[53]
110-2450	New York City (NYC)	Urban gardens	[54]
8.96-100.29	Southeastern China	Urban and rural zones	[55]
159 -3867	throughout Australia	Roadside soils, Garden	[39]
110-2450	New York, USA	Gardens	[54]
13-616	Belgrade, Serbia	Duga paint and varnish factory	[56]
179.75-1704	Hezhang County, China	Artisanal zinc-smelting activities	[57]
54.2 - 4366	throughout Australia	Smelter	[38]
14.3-2000	East China	Battery plants	[58]
8.96-100.29	Southeastern China	Urban and rural zones	[55]
Northeast.: 0 to >100000 West.: 1-88176 Midwest.: 0-24672 South.: 0-190980	Throughout the USA	-	[59]
7.33 -433	Bangladesh	-	[60]

Status of lead in soils

Soil is both a sink and a source of different heavy metals [10]. Lead is one of the most widely and evenly distributed trace metals that exist in various forms in natural sources. Lead, which was deposited in the past, can still be a problem today because it neither biodegrades nor breaks down at an appreciable rate under normal environmental conditions [38]. Pb bio-accessibility is influenced by Pb contamination sources, soil properties, and particle size fractions [39]. Contamination of soil with Pb poses a risk to ecosystem health, particularly organisms in direct contact with the soil. Pb concentrations widely differ in various soils of the world. This property is closely associated with the differing strengths of lithologic and anthropogenic sources, output and urban development, and increasing population density pattern [10]. Humans are exposed to Pb compounds through various pathways such as dermal contact, ingestion of soil and water, inhalation of dust, and consumption of vegetables grown in contaminated soil.

Table 3. Lead (Pb) concentration (mg/kg dry weight) in some crops

Plant Species	Scientific Name	Concentration	Region; Pb Content in Soil (mg/kg Soil)	Ref.
Spinach	*Spinacia oleracea*	1.15-2.93	Shiraz, Iran; 144.4	[43]
Lettuce	*Lactuca sativa*	1.36-3.23	Isfahan Province, Iran; 12.62-363	[61]
Celery	*Apium graveolens)*	0.01-0.09	Shiraz, Iran; 144.4	[43]
Celery	*Apium graveolens*	0.05-0.06	Isfahan Province, Iran; 12.62-363	[61]
Radish	*Raphanus sativus*	0.25-2.71	Isfahan Province, Iran; 12.62-363	[61]
Radish	*Raphanus sativus*	0.3	Sanandaj, Kurdistan, Iran; 25.4	[62]
Cabbage	*Brassica pekinensis* L.	0.04-15.25	Isfahan Province, Iran; 12.62-363	[61]
Coriander	*Coriandrum sativum*	0.64-1.89	Isfahan Province, Iran; 12.62-363	[61]
Dill	*Anethum graveolens*	0.42-2.21	Isfahan Province, Iran; 12.62-363	[61]
Coriander	*Coriandrum sativum*	0.4	Sanandaj, Kurdistan, Iran; 25.4	[62]
Dill	*Anethum graveolens*	0.4	Sanandaj, Kurdistan, Iran; 25.4	[62]
Radish	*Raphanus sativus* L.	5.0	Egypt; 300	[63]
Lettuce	*Lactuca sativa*	2.0	Egypt; 300	[63]
Rice grain	*Oryza sativa* L.	0.01-14.58	Isfahan Province, Iran; 12.62-363	[61]
Rice grain	*Oryza sativa* L.	0.07-35	Throughout Iran	[64]
Wheat grain	*Triticum aestivum* L.	0.03-1.11	Isfahan Province, Iran; 12.62-363	[61]
Wheat grain	*Triticum aestivum* L.	0.12-0.87	Shazand County, Iran; 12.40-452	[42]
Wheat grain	*T. aestivum*	24.45-26.23	Shiraz, Iran; 441.7	[43]
Barley grain	*Hordeum vulgare*	0.09-0.42	Shazand County, Iran; 12.40-452	[42]
Maize grain	*Zea mays* L.	0.01-2.58	Southwest China; 179.75- 1704	[57]

Pb pollution levels in soils can be evaluated in terms of the Enrichment Factor (EF), the geo-accumulation index, and the Contamination Factor (CF) [40]. A common method in risk assessment of metal contamination is to compare present concentrations with critical concentrations at which adverse effects are expected. The maximum allowable concentrations for trace metals vary greatly depending on land use and differ significantly between countries [41]. If the control level is exceeded, further measures must be taken to identify and manage potential risks.

In this section, we also reviewed the total Pb content in soils from diverse landscapes and ecosystems throughout the world, including urban and suburban areas, mining regions, recreational and industrial areas, agricultural land used for crops or grazing, etc. These conditions are summarized in Table 2. Based on the obtained data, the highest concentration of lead in the soil was found in Southern USA in old and industrialized urban cities (New Orleans, LA (urban): 190, 980 mg/kg) and in China, close to a lead and zinc smelting plant in Qili Village (Sanming, in the Youxi zone: 30,430 mg/kg). In addition, the range of Pb concentrations for agricultural soils in different regions is summarized in Table 2. Based on the obtained data, the concentration range of Pb in agricultural soils of Iran was from 2.4 (Khuzestan Province) to 642.5 (agricultural lands around the Nakhlak mine, Arak Province). More details are summarized in Table 2. In many countries, the allowable concentration in agricultural soil for Pb is adopted on national levels to regulate the management of contaminated land [41]. In agricultural soil of Iran, the Environmental Protection Organization of Iran addresses Pb with allowable levels of 50 mg/kg in soils with pH<7; and with allowable levels of 75 mg/kg in soils with pH>7 (Iranian Environmental Quality Standard [IEQS] in 2013).

Status of lead in plants

The rapid increase in population and the growing demand for food have increased the cultivation of crops on polluted or contaminated lands, including those close to industries, mining areas, and so on [42]. In addition, the indiscriminate use of agrochemicals, such as pesticides, fertilizers, and insecticides, and the use of sewage sludge and untreated industrial wastewaters make this problem worse [43]. Increasing evidence shows that the cultivation of crops on contaminated land can potentially result in the transfer of Pb from soil to the edible part of a food crop [42, 44, 45]. This condition may also threaten the health of animals and human beings through the food chain. Hence, seeking information about the Pb level in crops and their dietary exposure is essential for assessing risk to human health. In this section, we reviewed some studies carried out on the Pb content in various crops in some regains and especially in Iran. These data are summarized in Table 3. Pb contents in the crop in most of the studies were compared with food safety standards given by the Joint FAO/WHO Expert Committee on Food Additives (JECFA 2005, 2014), the Food and Agriculture Organization, the World Health Organization (FAO/WHO, 2001), and the National Food Hygiene Standard of China (NFHSC). In Iran, when Pb levels in the crops (vegetable and cereal) are compared with the permissible levels required for safe food (set by FAO/WHO 2001), a substantial divergence from these permissible limits will be observed, especially in Isfahan Province (Table 3).

Lead remediation techniques from the environment

Contaminated soils may be risky for living bodies. Heavy metals are of serious alarm among different soil pollutants due to their potentially toxic and carcinogenic effects, nature and chemical behaviors, and restricting the use of different remediation strategies.

There are different strategies for remediation of heavy metals in contaminated soils, depending on soil and plant techniques (Figure 3).

In the soil methods, ex-situ and in-situ remediation techniques are defined, whereas in-situ techniques are more usual and focus on three procedures: isolation, removal, and stabilization [65]. Isolation techniques are employed to decrease pollutant mobility by lowering the surface area, decreasing the soil permeability, and or decreasing the pollutant mobility. Remediation techniques eliminate contaminants from a polluted site by using physical or chemical processes. In the stabili-

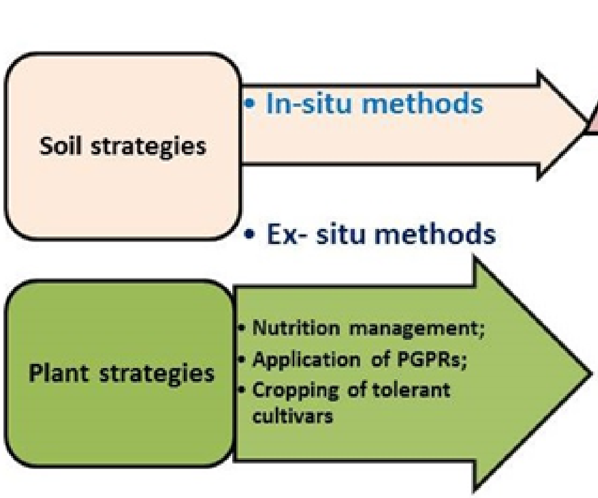

Figure 3. Remediation techniques for heavy metals in contaminated soils

zation techniques, chemical amendments and or plants are employed to decrease the metal's bioavailability in contaminated soils. The important in-situ remediation techniques are discussed below.

Stabilization/solidification

The stabilization/solidification technique reduces the bioavailability of trace metals via a chemical additive [66]. This technique can be performed by treating with chemical inputs that restrict the solubility/mobility of contaminants and entrap the contaminants within the soil [66]. Traditionally researchers have studied the usefulness of different inputs on Pb stabilization. Among the different inputs, lime-based stabilization/solidification techniques have proven to manage Pb significantly. Furthermore, Cao et al. [67] showed that rock phosphate was very useful for stabilizing Pb in contaminated sites.

Vitrification

Vitrification includes using an electric current to dissolve soil at high temperatures (1600 to 2000°C), inducing the soil to form a stable, glass-like matrix in which most inorganic pollutants are stabilized [65]. Organic pollutants are usually volatilized or pyrolyzed through this process. Because of its high cost, vitrification is the best technique for heavily contaminated soils with a mixture of different pollutants. Generally, vitrification is recommended for soils having nonvolatile trace elements at concentrations that are not more than their glass solubility [68]. The success of vitrification for remediation of Pb in soils will rely on the challenge of keeping the metal within the melt and the capability to manage volatile releases. The polluted sites must also have enough glass-forming compounds [68].

Electrokinetic technique

The electrokinetic technique involves putting electrodes inside the subsurface and using a low-intensity direct current in the soil to encourage electrochemical and electrokinetic reactions to desorb elements from the soil and adhere them to the electrodes for removal or remediation [69]. This process produces an acid around the anode that finally transfers from the anode to the cathode, increasing the desorption/dissolution of the pollutants from the soil [70]. This technique is usually used to accumulate the metal pollutants at or near the electrode. Based on Federal Remediation Technologies Roundtable (FRTR) [71], these contaminants can be removed through excavation, electroplating at the electrodes, precipitation at the electrodes, water pumping near the electrode, or binding/complexing with ion-exchange sites.

Soil flushing

The soil flushing technique includes using water (or other appropriate solutions) to remove pollutants from the soil [71]. The efficiency of metal-remediation under soil flushing correlates with the amount of contact between the extraction fluid and the polluted soil matrix, the metal mobility in the extraction fluid, and the metal propensity to absorb/adsorb to the soil matrix the metal-laden extraction fluid transfers to the extraction point. This technique is also most suitable for moderately uniform and permeable soils [70].

Ethylenediaminetetraacetic acid is the most commonly studied reagent for increasing the extraction of Pb from soils, and reports have shown its potential usefulness [72]. A series of other extractants, including diethylenetriaminepentaacetic acid, citrate, oxalate, and cyclodextrin, have been studied with different degrees of efficiency [14].

Phytoextraction technique

Phytoextraction refers to using heavy metal-tolerant plants with the potential to absorb and accumulate trace metals from the soil into the plant tissues. It includes the extraction of the pollutant from the soil via up-take and possibly, recovering the metallic elements by melting the plant tissues. The ideal plants for phytoremediation should develop on metal-bearing soil, have considerable biomass and growth, uptake and endure considerable levels of toxic elements, and have the potential to absorb numerous elements and show resistance to diseases and pathogens [73]. The success of phytoextraction relies on several factors: the amount and chemical forms of the toxic metal, the type, strength, and delivery efficiency of conditioning fluids (if used), and the growing conditions [65].

Chemical stabilization

Conceptually, chemical stabilization parallels in-situ stabilization/solidification techniques. The main difference between chemical stabilization and stabilization/solidification techniques is that the chemical stabilization technique includes the application of commonly nonconventional chemical improvers to cause specific chemical reactions within the soil matrix that transform the pollutants into nontoxic or non-bioavailable and or fixed forms. Unlike many stabilization/solidification technologies, chemical stabilization does not encapsulate the toxic element or decrease the permeability of the amended soil matrix. Typically, the chemical stabilization technique includes lesser improver application rates relative to the stabilization/solidification technique and, therefore, does not significantly change the soil properties [65].

Phytostabilization

The phytostabilization technique refers to apply plants, separately or in combination with soil improvers, to immobilize trace element-contaminated soil by restricting the element's mobility and phytoavailability [65]. Dissimilar to phytoextraction, during a phytostabilization process, plants usually do not concentrate the contaminants in their shoots, which could be consumed by human or ecological receptors [74]. Generally, the phytostabilization technique is useable in soils with extensive surficial pollution where trace elements exist in the soils at low concentrations. The most usual and encouraging phytostabilization method is the simultaneous application of plants and soil improvers to amend toxic element-contaminated sites. The majority of the phytostabilization studies have used biosolids, with or without additional chemical improvers.

There is also another technology for remediation of contaminated soils, known as bioremediation. Because microorganisms have developed different approaches for endurance in toxic metals-contaminated sites, they are being recognized for use in numerous cleaning strategies, including biosorption, bioaccumulation, biotransformation, and biomineralization, which can be used for bioremediation [34].

2. Conclusion

Heavy metals enter the environment from various sources, especially anthropogenic activities, posing a severe threat to public health by entering the food chain. Among heavy metals, lead (Pb) is important due to its application in various industries, entering the environment through various agricultural activities and combustion of fossil fuels. Another reason for the importance of paying attention to heavy metals is the fact that they are non-biodegradable in the environment and also many diseases and dangers they pose to living creatures. Because of the population growth, food crisis, and expansion of industrial and agricultural activities, the entry of these metals into the environment is inevitable. Although there are numerous methods to remove these pollutants from the environment, it is easier and cheaper to use the correct and scientific management methods to prevent or reduce their entry into the environment. Therefore, more studies are needed to monitor and control their entry into the environment.

Ethical Considerations

Compliance with ethical guidelines

There were no ethical considerations to be considered in this research.

Funding

The authors did not receive any financial support for the research, authorship, or publication of this article.

Authors' contributions

Conceptualization and Supervision: Seyed Majid Mousavi; Methodology: Seyed Majid Mousavi, Kamal Payghamzadeh; Investigation, Writing-original draft, and Writing-review & editing: All authors; Data collection: Seyed Majid Mousavi, Kamal Payghamzadeh, Tahereh Raiesi; Data analysis: Seyed Majid Mousavi, Anoop Kumar Srivastava.

Conflict of interest

The authors declared no conflict of interest.

Acknowledgments

The authors appreciate the Soil and Water Research Institute, Agricultural Research Education and Extension Organization, Karaj, Iran, for supporting this research.

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