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Review

A Review on Cadmium and Lead Contamination: Sources, Fate, Mechanism, Health Effects and Remediation Methods

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Abstract: Cadmium and lead soil contamination is a widespread environmental problem that requires profound and sustainable solutions. These toxic elements can be naturally occurring on the Earth's crust or from man-made origins. Cadmium and lead could accumulate and translocate in soil over the long term. Thus, their risk of entering the food chain is extremely elevated and their effects on the living organisms in the food web are of great concern. The main purpose of this review study is to emphasize the risk to human health of cadmium and lead as an environmental contaminant in soil and plants. Human exposure to cadmium and lead can cause severe illness; for instance, long-term exposure to cadmium can alter kidney health and cause dysfunction. Additionally, lead threatens the nervous system and causes countless diseases. Hence, the remediation of cadmium and lead from soil before they enter the food chain remains essential, and regular monitoring of their principal sources is crucially needed for a sustainable soil ecosystem.

Keywords: cadmium and lead contamination; anthropogenic source; soil and plant; public health; diseases

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1. Introduction

Since the beginning of the industrial revolution in the late 18th century, pollution has become one of the biggest issues in the world. This is due to rapid development of industrialization, urbanization, and agriculture worldwide. Cadmium and lead contamination has emerged as a global concern and gained the scientific community's attention owing to its potential risk for the environment and human health. This sort of contamination may spread into different parts of the Earth's system namely, biosphere, atmosphere, lithosphere and, hydrosphere [1]. Recently, with the developed techniques and methods for monitoring these chemicals, it has been found that exposure to these metals in low quantities can contribute to various diseases and even death. However, cadmium and lead have been heavily reported in the literature as polluting several environmental components, such as soil, plants, water and air. They are either naturals (geogenic) from parent rocks and mineral sources that present naturally on the Earth's crust or from man-made sources (anthropogenic) including agriculture (agrochemicals), metallurgy, energy production, and the disposal of sewerage [2]. For instance, in Southeast Asia, the population has increased too fast over the last decades, imposing enormous requirements for expansion of industrial and economic plans [3]. Therefore, farmers look to fulfil the population food demand by adding fertilizers and pesticides, and by irrigating soil with untreated wastewater which contributes to cadmium and lead accumulation in both soil and food plants.

Soil cadmium and lead contamination is one of the most critical matters and numerous investigations have demonstrated their contamination levels in soil [4–10]. Soil is a living environment where different organisms such as bacteria, fungi, and others can live. A healthy soil provides a healthy environment to other organisms to live and to accomplish their biological and chemical functions. Nevertheless, the presence of a contaminant can destroy this ecology and lead to a diminution in soil quality. This sort of contamination affects the fertility of the soil, and thus, the quality of the environment and the food that will be harvested from it. The plants and food crops that have been grown in this contaminated zone may probably be contaminated too. Soil and plant represent a system where various interactions and operations take place, such as nutrient intake from the soil by plants; contamination of soil and food systems with cadmium and lead is a progressive concern because of its possible risks to human health, animal health, and environmental quality [11] arising from different environmental origins [12–16]. Hence, the toxic elements would be introduced into the food chain and cause a ubiquitous problem to human health. Their entry to the food chain is a complicated process where too many factors may play a vital role such as the soil properties, type of plant, climate conditions and other factors that influence the distribution and accumulation of cadmium and lead in food and soil. In order to manage any cadmium/lead contamination, many methods and strategies have been proposed to extract these contaminants from soil such as electrokinetic treatment, soil washing and leaching, soil immobilization, nanotechnology, and phytoremediation [17–19]. Moreover, the remediation method must be carefully selected based on its high effectiveness in cadmium and lead removal, low cost, and suitability for large-scale implementation.

A greater knowledge of cadmium and lead contamination mechanisms will help in the discovery of a method to remove or minimize their presence in soil and plants. To achieve this purpose, it is necessary to understand their sources and ability to accumulate and translocate in the different parts of the environment. Hence, the present review aims to emphasize:

i. The source of cadmium and lead in soil and food plants.
ii. The accumulation mechanism and fate of cadmium and lead in soil and plant systems.
iii. The human health risks resulting from cadmium and lead accumulation and exposure.
iv. The possible remediation technologies.

2. Methods and Scope of Study

This study is based on a literature review from across the world and aims to emphasize the sources of cadmium and lead in soils from different land uses, and different types of plants (grains, crops, medicinal plants) as well as their concentration levels compared to the allowable standards set by FAO/WHO and other screening levels from China, Europe, Malaysia. To achieve this goal, the authors used a scientific database (ScienceDirect) to extract the related research studies using keywords such as "cadmium/lead contamination in soil, plant, or soil-plant system", "health effects of cadmium and lead from dietary exposure", "remediation and mitigation methods of cadmium/lead contamination in soil". The results were filtered in the specific period (2015–2021) with the focus on the very recent studies (2020/2021). The reason behind using only cadmium and lead as the criterion for search is that both elements have been repetitively mentioned in the literature owing to the high potential risk caused to environment and public health. The primary selection of articles was based on several criteria such as publication date of the article, the contaminants (cadmium or lead only), cadmium and lead concentration ranges in soil and plants only). Then a secondary selection was conducted with the focus on the abstract, the finding, and the compatibility of the article with our research question/objectives as shown in Figure 1.

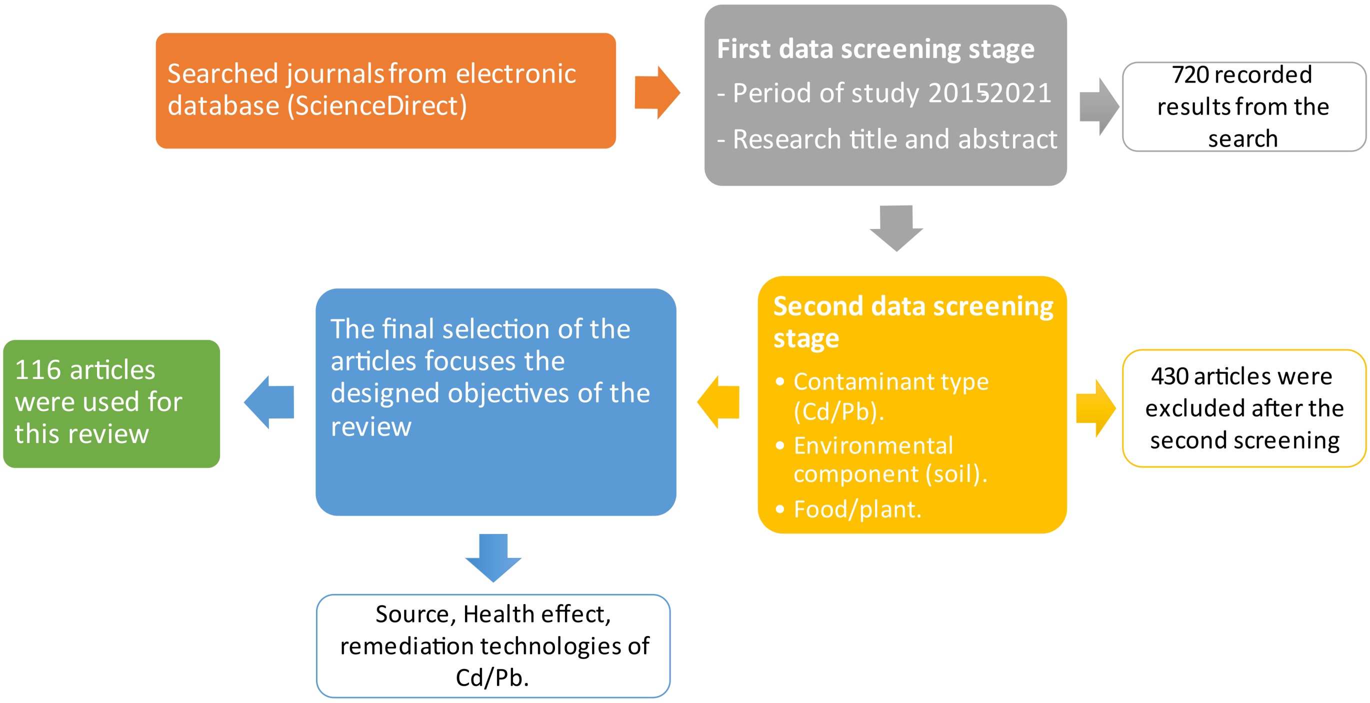

Figure 1. The process of selection of journal articles.

3. Sources of Cadmium and Lead in Both Soil and Plants

In general, heavy metals are either generated from natural sources such as volcanoes, rocks, and parent materials or man-made sources, such as industrial factories, agrochemicals application, wastewater irrigation and other origins, as shown in Table 1. Further, a very low level of cadmium and lead occurs naturally in the soil from several geogenic sources such as weathering of parent materials that formed the soil as reported in [20]. However, higher levels of cadmium are detected in some locations such as Kampung Pinang, Kota Sawarahan, and Sarawak in the natural soils. Otherwise, a huge part of the cadmium and lead in soil has been reported to be anthropogenic (Table 1).

Soils from different backgrounds have shown different contamination origins depending on the potential heavy metals sources in the surroundings. Several investigations have revealed the main source of the cadmium/lead contamination in their study area. Cadmium and lead were found to be generated from industries. According to the findings of [21], industrial production is the most significant source of anthropogenic cadmium emissions in Southeast China, accounting for 62.1% of total emissions. Factories tend to release thousands of tons of toxic metals; the circle starts from the factory itself to terminate at the surface soil and plants. For instance if a coal power plant releases a considerable number of contaminants to the atmosphere, some of them would be deposited on the soil-plant system, while some may reach this system through many other paths such as solid waste and wastewater. As one contamination source has too many pathways to reach the soil-plant system, what if we have multiple pollution sources at once? A study conducted in India on soil from agricultural fields producing wheat, rice, maize, greens, and mustard seeds [22] showed multiple sources of heavy metals namely, thermal power plant, cement factory, and agrochemicals application as illustrated in Figure 2. However, the finding in this research study demonstrates that cadmium and lead in that region provide a non-cancer health risk to the people. Likewise, according to [23], in Shanghai, China, toxic elements in leafy vegetables, agricultural soils, and road dust have been detected to be from coal-fired plants, stationary industrial emissions, and municipal waste incineration emissions. The outcome validates that the quantity of cadmium and lead contamination varies according to metal species, location, and environmental medium. Moreover, metallurgical refining of ores may release a hazardous waste and this may raise the risk of metals contamination if the waste is not well managed. For instance, a study reported in [24] confirmed this by investigating the slag generated from processes for refining Zn and Pb; the findings revealed that the slag under consideration was a very diverse type of waste, including high levels of heavy metals, and is poisonous. In the event that waste is not disposed properly, landfills can also receive significant amounts of cadmium and lead and many other metals. The possibility of metal transportation to the landfill is elevated due to convenience factors. Effective waste management can aid in preventing metals from leaching into soils and groundwater. Atmospheric deposition has been detected to be one of the major pathways of cadmium and lead contamination in the soil-plant system, due to the chemicals emitted from different industrial factories sites; the metals may be attached to small particles and spread in the air and enter different environmental compartments through a biogeochemical cycling of contaminants in the earth system known as wet/dry deposition whereby chemicals can be deposited on terrestrial and aquatic surfaces, affecting the physicochemical nature of the system. Mines and smelters were principal contributors to high amounts of heavy metals on topsoil from Hezhang County, Southwestern China: research has shown that the high quantities of cadmium and lead were related to large iron and lead-zinc mines which made a 27.37% contribution, according to positive matrix factorization (PMF) analysis [25], an effect which is most likely promoted by atmospheric deposition. Various studies have documented the effects of atmospheric deposition of heavy metals especially lead and cadmium, highlighting the harmful consequences of their accumulation on the soil-plant system [22,26–29]. Other than the soil-plant system, a study conducted on Chinese natural terrestrial ecosystems (forests, grasslands, deserts, lakes, marshes, and karst ecosystems) showed that oil consumption, number of vehicles, and coal consumption were the main factors that influenced atmospheric wet deposition. The cadmium and lead contents in soil were shown to be positively linked with the wet deposition of cadmium and lead [30] and this explains that coal, oil consumption as well as the traffic density are the origins of that contamination through the process of atmospheric deposition. Coal power generation has been detected to have massive impact on the surrounding soil which was strongly contaminated by cadmium and uncontaminated by Pb [31]. However, the ecological risk remains elevated and the trace elements, according to the finding, are credibly produced from an anthropogenic source. Identically, [32] reported that cadmium concentrations were extremely high in a coal mining city (Lianyuan, China); the measured atmospheric deposition fluxes showed their highest levels at industrial areas. The soil content of cadmium was observed to be elevated in the high density coal mining environment and was positively correlated with cadmium in the Lianyuan city's atmosphere. Contrarily, a finding of [33] reporting on pakchoi (*Brassica chinensis* L.) showed that the presence of cadmium in its edible shoot near the copper smelter resulted from freshly deposited metals in the environment, resulting in a greater health risk from pakchoi consumption. Nevertheless, other sources remain important since they are all considered as environmental threats such as traffic density; the released lead emissions from intensive traffic are of great concern. The spillage of fuel and diesel during transportation can lead to soil pollution. Many studies have investigated the cadmium/lead levels in roadside soils and they confirmed that the elevated values are due to vehicle traffic [34–36].

Agrochemicals application is one of the principal sources of heavy metals in agricultural soils and plants. Inorganic fertilizers are the main contributors of heavy metals, especially phosphate-based fertilizers which can enrich the soil with cadmium, lead, and other heavy metals in the long term. An extensive use of those chemical substances to increase the quantity/quality of the harvested food will decrease the quality of the soil and damage the microbial community; this may alter the biogeochemical functions of the soil as a living organism and cause a huge disruption to the system. Previously, certain investigations regarding this matter have shown fertilization as the major contributor to heavy metal contamination [37–39]. Further, there are countless origins of cadmium and lead contamination that may reach the soil-plant system and cause harmful consequences either directly or in directly.

Table 1. Cadmium and lead contamination in soil and plants from a variety of sources.

Plants	Soil	Origin of Cd/Pb in That Region	Summary and Main Finding	Reference
Elytrigia repens *Galium verum* *Phragmites australis* Wildflower	Composite soil from surface and subsoil layer	Estuarine floodplain pollution (human factors)	The study revealed the anthropogenic source of heavy metals in the surface soil, and it was found that heavy metals can be mobilised by root exudates and become phyto-available, as shown by the increased plant uptake of HMs due to their non-soluble nature.	[40]
Rice, Chinese cabbage, Spinach, Cowpea	Paddy fields, vegetable field, dumping site, burning site, and acid leaching site	Abandoned e-waste recycling site	The study showed that pond water was utilized for irrigation, crops on agricultural fields can be polluted, which would have a negative impact on human health after being consumed. Aquatic life in the pond had become highly acidified and polluted with heavy metals due to previous recycling activities.	[41]
Bok choy Water spinach Shanghai green cabbage Leaf lettuce	Agriculture soils and road dust	Coal-fired plants, Stationary industrial emissions, Municipal waste incineration emissions.	The finding of this study highlighted that the amount of heavy metal pollution varies with metal species, location, and environmental medium.	[23]
Woody, shrubby, and herbaceous plants species	Non-farmland soil (Pb smelter)	Heavy metals emissions from Pb smelter	The finding showed that plants with lower BCF values may be able to be reproduced and seeded in polluted areas, which might minimise heavy metal build-up in the food chain.	[42]
Rice grain, corn kernels, and vegetables	Soil (rhizosphere part)	Smelting-mining. Vehicle emissions from diesel fuels. Atmospheric dust fall.	The study revealed that the amounts of HMs found in the soil-dust-fall plant system in the investigated area varied depending on the metal type and the environment. Compared to corn kernels, rice grains have a greater potential to enrich HMs.	[29]
(Wheat, rice, maize) grains, mustard seeds	Soil from agriculture fields	Thermal power plant (fly ash deposition). Agrochemicals application. Cement factory.	An investigation of HMs concentration in crop fields near to a thermal power plant; the final finding shows that HMs in that area cause a non-cancer health risk to the residents.	[22]
Brown rice	Soil near three mine areas	Nonferrous metal industry Mining and smelting	The investigation revealed the hyperaccumulation tendency of HMs in rice grains particularly in mining areas; rice has been identified as a major source of heavy metal exposure.	[43]
-	Soil from different land use (aquacultural pond, barren land, built-up land, dry land, inland halophyte, intertidal flats, open water, reed marsh and rice paddy)	Industrial and agricultural wastewater discharge, domestic sewage discharge, atmospheric deposition.	As a result of these findings, heavy metal concentrations in soil and sediment of a long-term reclaimed region might be affected by land-use intensity differences. It was shown that soil characteristics such as soil organic carbon and grain size had a significant impact on the dispersion of heavy metals.	[27]
Rice grain (*Oryza sativa* L.)	Agricultural soil/agrochemicals	Agrochemicals	The finding demonstrated the correlation between cadmium concentration and the soil pH when the increased level of cadmium is related to the decreased soil pH. Furthermore, some traditional cultivars, including Pachcha Perumal, consistently shown very high resistance to cadmium absorption in both seasons. When compared to other farmed types, the Madathawalu and Kuruluthuda cultivars were relatively resistant.	[44]

Table 1. *Cont.*

Plants	Soil	Origin of Cd/Pb in That Region	Summary and Main Finding	Reference
-	Chinese Natural ecosystems (agricultural, aquatic, desert, forest, grassland, Karst ecosystems)	Atmospheric deposition from oil and coal consumption. Number of vehicles	In this study, the wet deposition of lead and cadmium was shown to be positively linked to cadmium and lead soil concentration which confirms the atmospheric deposition origin of HMs in that region.	[30]
-	Surface soil	Atmospheric deposition from coal combustion, chemical factories, iron and steel smelting, heavy traffic.	The results showed that cadmium air deposition fluxes were highest in a coal mining area and significantly lower in a rural area. Coal combustion connected to chemical and metallurgical industries was identified as the primary cause of cadmium pollution in Lianyuan city's atmosphere.	[32]
-	Peri-urban agricultural soils	Fertilization and atmospheric deposition	The investigation revealed that the intensive agricultural output led to the build-up of heavy metals in the soil, a reduction in soil pH, and an increase in soil organic matter content (SOM) and according to the results of the lead isotope ratio analysis IRA, input fluxes analysis (IFA), and positive matrix factorization (PMF) models, air deposition and fertilization were the primary causes of heavy metal accumulation in soils.	[28]
Pakchoi (*Brassica chinensis* L.)	Soil reciprocal (designed for the experiment)	Atmospheric deposition from copper smelter	The study showed that the substantial proportion (20–85%) of cadmium, and lead discovered in the edible shoot of pakchoi near the copper smelter was caused by freshly deposited metals in the atmosphere, which also resulted in a higher health risk of pakchoi intake. These findings demonstrated that the function of freshly deposited heavy metals was critical in the risk management of heavy metal pollution in soil-vegetation systems.	[33]
-	Urban road surface	Direct deposition of lead on the urban road	The results show that lead contributed to road build-up and the atmosphere by the soil along the road that has been disturbed by natural and traffic-induced wind. In comparison to atmospheric deposition, direct deposition is the most common route for lead to reach the roadways.	[45]
-	Agricultural soils	Agrochemicals, atmospheric deposition and industrial emissions, sewage irrigation, leather tanning industry.	This resource-based region's agricultural soils were extensively contaminated with lead and cadmium. The primary causes of contamination were human activities such as agriculture and sewage irrigation, as well as industrial and atmospheric pollutants.	[46]
Vegetables and grains	Agricultural soils	Weathering of parent materials, phosphorus fertilizers	The overall finding showed that heavy metal contents in soil are naturally occurring and due to basaltic parent material, that forms the soil, and it increases with the increase of the weathering duration. In addition, the usage of phosphorus fertilizers may have altered the cadmium content of the soil.	[38]

Table 1. *Cont.*

Plants	Soil	Origin of Cd/Pb in That Region	Summary and Main Finding	Reference
-	Agricultural soil	Agrochemicals and fertilization	The various accumulation patterns observed in wheat field soil revealed that the accumulation level of HMs and REEs in the soil is connected to the continuous application of fertilizers, in addition to pesticides and herbicides, over time.	[37]
-	Soil from shallot fields	Long-term fertilization, pesticides, organic manure. Parent materials.	In this study, cadmium concentrations are induced by agricultural activities such as long-term applications of animal manure, insecticides, and phosphorus fertilizers. The lead concentration of the agricultural soils is thought to be controlled by natural sources such as lithogenic factors and parent materials.	[39]
-	Agricultural soil	Agrochemicals, atmospheric dust, traffic density Fossil fuel combustion from gas and oil fields nearby, transported by dust storms. Non-crustal sources.	According to the results obtained from PERI, cadmium contributed 97.2% to the total potential ecological risk in the soils. Cadmium concentrations in soil samples above background values for continental crust and average global soils.	[47]
Carrot and cabbage	Carrot and cabbage soil	Wastewater irrigation, fertilizer application	The results revealed that both the cabbage and carrots, as well as the soils, had heavy metal levels over the threshold standards specified by international organizations regulating food safety. The intensive application of fertilizers resulted a decrease in pH and organic matter production rates in soil.	[48]

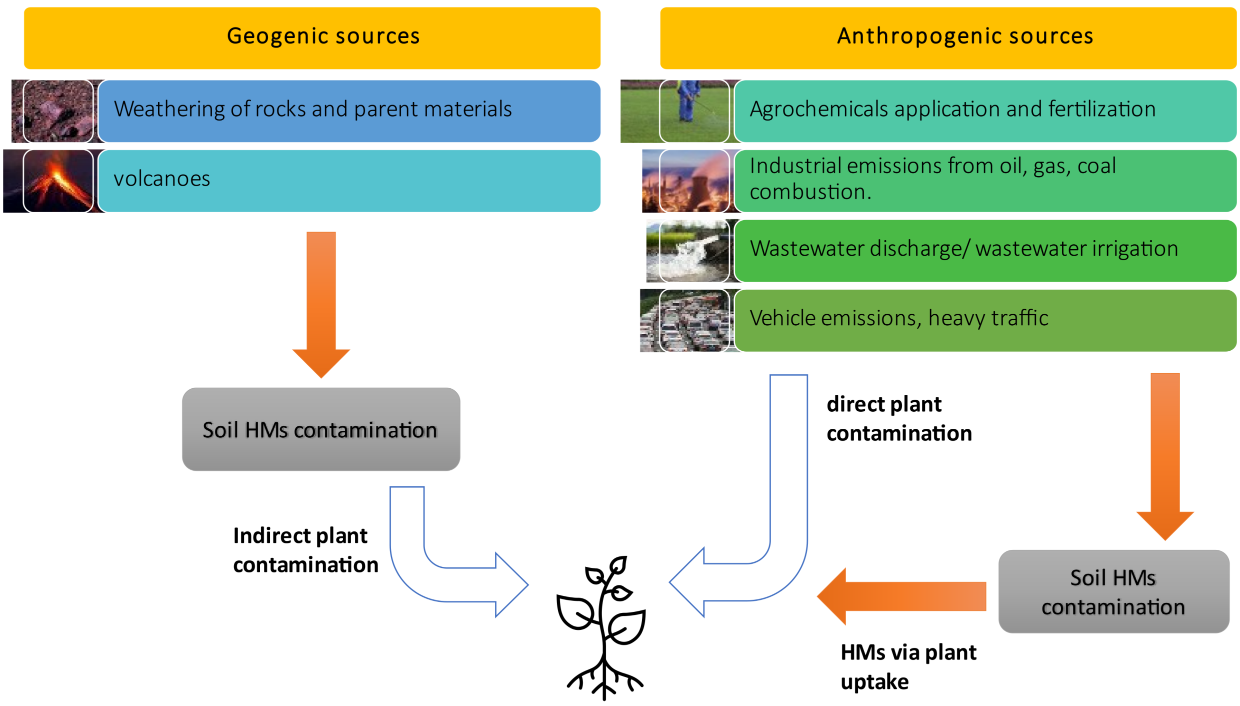

Figure 2. Principal origins of cadmium and lead contamination in soil-plant system.

4. Cadmium and Lead Contamination Levels in Different Types of Soil and Plant

The occurrence of hazardous metals on the surface soil can have adverse effects on public health and result in poor quality of the harvested food. In the last few years, studies have highlighted the destructive effect of such contaminants by detecting their presence in all the types of land use (agricultural, urban, industrial) and plants, and have identified the environmental factors that support the metals accumulation in soil as well as food plants.

In general, the soil/plants content of heavy metals is the result of human activities. Cadmium and lead are not essentials for both soil media and plant growth and can be harmful. Therefore, for good monitoring practices and quality assurance/control requirements, the measured levels of cadmium and lead in any sample must be compared to a group of standards set by worldwide organizations such as: Food and Agriculture Organization (FAO/WHO), European Union (EU) and other organizations standards such as those from Malaysia and China, as shown in Table 2.

Table 2. Maximum levels for cadmium and lead in both food and soil from different organizations.

Organizations	Soil/Plant Types		Cd and Pb Standards	References
EU [a]	Soil	-	Cd 0.2 mg/kg	[49]
	Plant	Leafy vegetables, fresh herbs, celeriac, cultivated fungi	Cd 0.2 mg/kg	
		Stem vegetables, root vegetables, and potatoes	Cd 0.1 mg/kg	
		Vegetables and fruits (excluding leafy vegetables) and other products	Cd 0.05 mg/kg	
		Brassicas, leaf vegetables	Pb 0.3 mg/kg	
		Vegetables (including peeled vegetables)	Pb 0.1 mg/kg	
FAO/ WHO [b] (2007)	Soil	-	Cd 0.07 mg/kg, Pb 10 mg/kg	[48]
	Plant	-	Cd 0.2 mg/kg, Pb 5 mg/kg	[50]
SEQS [c]	Soil	-	Cd 0.3 mg/kg	[51]
AQSIQ [d]	Plant	Rice	Cd, Pb 0.2000 mg/kg	[52]
DOE [e] (2009)	Soil	Residential soil	Cd 7.0 mg/kg, Pb 4.0 mg/kg	[53]
		Industrial soil	Cd 8.1 mg/kg, Pb 8.0 mg/kg	

Notes: [a] EU = European Union, [b] FAO/WHO = Food and Agricultural Organization/World Health Organization, [c] SEQS = China Soil Environmental Quality Standards, [d] AQSIQ = Administration of Quality Supervision, Inspection and Quarantine of People's Republic of China, Standardization Administration of China, [e] DOE = Department of Environment, Malaysia.

4.1. Cadmium and Lead Contamination in the Soil Ecosystem

Cadmium and lead can be naturally occurring in different types of soils, attributable to materials that formed the soil thousands of years ago. Nevertheless, in most of the reviewed articles, the soil heavy metal content was from diverse anthropogenic activities.

In Malaysian lands, cadmium concentration ranges were slightly higher than levels detected in most of the previously reviewed studies. For instance, in Melaka and Negeri Sembilan the cadmium (171.72 mg/kg) level from non-sanitary soil exceeded the standards set by FOA/WHO, DOE, EU [54], being affected by waste/leachate in non-sanitary waste dumps. This leads to soil contamination by heavy metals because of this garbage dumping in the region and the absence of landfill liner. The reviewed soils from other regions were mostly about the paddy soils (China). Paddy fields are the more assessed land type in Asian countries, since rice is the staple food for 90% of the population there and the paddy soils may be exposed to the risk of heavy metal contamination. The cadmium concentration range was high in Hunan (China), Yangtze Delta (China), Guayas (Ecuador), with levels of 0.228–1.91 mg/kg, 0.45 mg/kg, and 0.26–0.15 mg/kg, respectively. Therefore, the intensive application of fertilizers in paddy fields may be one of the main contributors to cadmium accumulation in the soil.

Lead was relatively less detected in some areas, as its main source is credibly man-made. Its ability to accumulate in the soils is still related to various aspects that might help its soil enrichment. As shown in Table 3, most of the studied regions have extremely high lead ranges that exceed the maximum levels set by all the organizations mentioned in Table 2. The smelting mining is known to be one of the origins of lead in different land uses, even the abandoned mines still contain considerable quantities of lead in their topsoil, and this creates an infinite risk to the surrounding areas. The lead values from different land uses in Poland were recorded to be extremely elevated where there was nearby mining and metallurgical activity [55]. The affected zones might not be used for any other activities especially agricultural ones until they progress to a profound removal of soil lead contents. For instance, lead concentration level in a bauxite mining area was detected to be 44.76 mg/kg in Kuantan Port and Bukit Goh, Pahang [56] and it is higher than the threshold values. Likewise at Kuala Lipis in Pahang State, Malaysia, levels of lead ranged from 63.5 to 72.5 mg/kg in surface soils from active and abandoned iron ore mining sites [57]. Other than industrial lands, agricultural soils were also exposed to high lead values from agrochemicals application as shown in Table 3.

Table 3. Cadmium and lead concentration ranges in different soils from previous studies.

No.	Location	Cadmium/Lead Concentration Range (mg/kg)	Land Use	References
		From Malaysian lands		
01	Klang district, Selangor	Cd (0.77 mg/kg) Pb (52.73 mg/kg)	Urban soil	[58]
02	(Kg. kubang and Kg. tok kambing) Kota bharu, Kelantan	Pb (7.396–11.30 mg/kg)	Soil from an agricultural area (cucumber crop)	[59]
03	Selangor	Pb (24.3–37.9 mg/kg) in landfill area Pb (14.5–27.9 mg/kg) in residential area Cd in landfill area (0.6–4.61 mg/kg) Cd in agricultural area (1.3–4.99 mg/kg)	Soil from Langat water catchment area (landfill, agricultural, industrial, residential)	[60]
04	Perlis	Pb (0.4 mg/kg) Cd (0.98 mg/kg)	Soil from the mango plantation area	[26]
05	Ranau Valley, Ranau, Sabah	Cd_{max} (2.83 mg/kg)	Soil from paddy field	[61]
06	Different sites from Peninsular Malaysia	Pb (0.05–0.09 mg/kg) Cd (7.8×10^{-4}–1.9×10^{-3} mg/kg)	Soil from Gotu Kola plantation	[62]
07	Kuala Lipis, Pahang	Pb (63.5–72.5 mg/kg)	Surface soils from active and abandoned iron ore mining sites	[57]
08	Kuantan Port and bukit Goh, Pahang	Pb (44.76 mg/kg) Cd (3.63 mg/kg) in Bukit Goh Cd (4.61 mg/kg) in Kuantan Port	The soil of bauxite mining area	[56]
09	Perlis	Cd (0.075 mg/kg)	Soil from 5 different sites (Jejawi, Kangar, chuping, kuala perlis, Beseri)	[63]
10	KKampung Sawah Sempadan, Tanjung Kanany, Selangor	Pb (6.64 mg/kg) Cd (6.00×10^{-2} mg/kg)	Paddy soil	[64]
11	Jengka, Pahang	Pb (0.03–4.60 mg/kg) Cd (0.01–0.32 mg/kg)	Soil from plantation area	[65]
12	Malaka and Negeri Sembilan	Pb (1.88 mg/kg) Cd (171.72 mg/kg) In non-sanitary sites	Soils from sanitary and non-sanitary sites	[54]
13	Yan, Kubang Pasu, and Pendang, Kedah	Pb (0.026–1.063 mg/kg) in Pendang area Pb (0.023–0.858 mg/kg) in Yan area Pb in Kubang Pasu (0.023–1.107 mg/kg) Cd in Pendang: (0.024–0.77 mg/kg) Cd (0.0018–0.013 mg/kg) in Yan Cd in Kubang Pasu: (0.001–0.152 mg/kg)	Paddy soils	[66]

Table 3. *Cont.*

No.	Location	Cadmium/Lead Concentration Range (mg/kg)	Land Use	References
		Lands from other countries		
14	Hunan, Southern China	Cd in soil (0.228–1.91 mg/kg)	Paddy soils	[51]
15	Northeast, Central and West, South, Yangtze Delta, China	Cd 0.45 mg/kg Pb 25.7 mg/kg	Paddy soils	[67]
16	Guayas province, Ecuador	Cd (0.26 ± 0.15 mg/kg) and Pb (13.52 ± 8.46 mg/kg)	Paddy soils	[68]
17	Zhejiang Province, China	Cd 0.126 mg/kg (background concentration, before adding Cd to experimental pots)	Paddy soils	[69]
18	Malopolska, Poland	Cd 0.01 to 16.9 mg/kg Pb 3 to 586 mg/kg (in topsoil)	Grassland, arable land, forest, wasteland	[55]

4.2. Cadmium and Lead Contamination in Plants

Generally, plants absorb the essential metals as micronutrients to maintain their growth such as iron (Fe) and zinc (Zn) but, inappropriately, other non-essential metals such as lead and cadmium are taken up by the plants and accumulate in roots and their edible parts what required consistent monitoring. The accumulation process depends on plant type first. Some food plants are proven to be accumulators of heavy metals, including leafy vegetables and rice grains [61,70,71]. Moreover, different parts of the plants may play a vital role in the accumulation of toxic metals, especially the roots in the rhizosphere where most of the biological and physicochemical processes happen. In the topsoil with 10 cm depth, high contamination levels of the toxic elements may occur and affect the roots of any plant type compared to greater depths where less contamination levels would be.

The accumulation of cadmium/lead does not affect soil or human beings only but can also inhibit plant growth and lead to the deterioration of the plant's health. Plants responses to cadmium/lead toxicity either morphologically or physiologically are subject to the amounts of the metals taken up and the type of plant. High quantities of cadmium and lead in any plant may lead to plant stress where its normal functions of photosynthesis and nutrient uptake would be threatened, and this may alter its growth, lower biomass, and cause chlorosis. On the other hand, the plant species that survive and are characterized as hyperaccumulators of heavy metals could be used as remediation agents or indicators of the cadmium/lead contamination. The ability to accumulate cadmium/lead is unwanted if the plant is to be consumed by humans due to the serious risk to health.

Diverse parts of the plants have been investigated to show which parts are able to accumulate cadmium and lead more effectively, as listed in Table 4. Roots from Centella asiatica and Athyrium esculentum showed lead concentration ranges of 0.022–0.037 mg/kg and 0.16–3.37 mg/kg, respectively. Where the lead concentration level in Athyrium esculentum from Jengka, Pahang was exceeding the reference values of the EU, this could be due to fertilizer use, since Jengka is known as a centre of agriculture in Pahang State, Malaysia.

Table 4. Cadmium and lead concentration ranges in different parts of the food plants from previous studies.

No	Location	Cadmium/Lead Concentration Range (mg/kg)	Food Plants	References
		In Malaysian regions		
01	Different sites from peninsular Malaysia	Pb-roots (0.022–0.037 mg/kg) Pb-shoots (0.016–0.025 mg/kg) Cd-roots (1×10^{-3}–1.7×10^{-3} mg/kg) Cd-shoots (4.1×10^{-4}–9.3×10^{-4} mg/kg)	Gotu Kola (*Centella asiatica*)	[62]
02	Ranau Valley, Ranau, Sabah	Cd (3.92 mg/kg)	Rice grain	[61]
03	Penang, Kedah and Perak	Cd-fruit vegetables (0.17–1.32 mg/kg) Cd-leafy vegetables (0.74–2.17 mg/kg) Pb-fruit vegetables (0.62–1.85 mg/kg) Pb-leafy vegetables (1.23–2.74 mg/kg) dw	Vegetables (leaves and fruits)	[70]
04	Jengka, Pahang	Pb-roots (0.16–3.37 mg/kg) Cd-roots (0–0.11 mg/kg)	(*Athyrium esculentum*) (*Chromolaena odorata*) (*Lantana camara*)	[65]
05	Pahang	Pb (0.79–1.46 mg/kg)	Bitter Gourd (*Momordica charantia)*	[72]
06	Jengka, Pahang	Cd (0.15–0.54 mg/kg) Pb (0.03–0.05 mg/kg)	Leafy vegetables Pak choi (*Brassica chinensis* L.) Amaranth (*Amaranthus gangeticus*) Caisim (*Brassica rapa* var. *parachinensis*).	[71]
07	Kampung Binjiai Manis, Kampung Aman and Bachok, Kelantan	Kampung Binjiai Manis: Pb in eggplant (3.44 mg/kg) Cd in Luffa (0.93 mg/kg) Kampung Aman: Pb in Eggplant (0.82 mg/kg) Cd in Luffa (1.12 mg/kg)	Eggplant (*Solanum melongena*) Chili (*Capsium annum*) Luffa (*Luffa acutangular*)	[73]
		In other countries		
08	(Devon, Cornwall, Aberdeenshire) Britain	High Cd in Spinach 0.04 mg/kg High Pb in blackcurrant 0.16 mg/kg	Fruits and vegetables	[49]
09	China	Cd (0.0025 to 0.2530) mg/kg Pb (0.0250–0.3830) mg/kg	Rice grains (*indica* and *japonica*)	[52]
10	United States (US)	Cd 3.15 mg/kg Pb 0.38 mg/ kg	Products originated from cocoa beans (cocoa powder, dark chocolate, milk chocolate, and cocoa nibs).	[74]
11	Zhejiang province, China	Cd 0.128 to 0.806 mg/kg	Rice cultivars	[69]
12	Chile	Lettuce (Cd 0.057, Pb 0.208 $mg/kg)_{max}$ Spinach (Cd 0.247, Pb < 0.263 $mg/kg)_{max}$ Chard (Cd 0.116, Pb < 0.238 mg/kg)	Lettuce, spinach, chard	[75]

5. Fate and Accumulation Mechanisms of Cadmium and Lead in Soil-Plant System

Metals derive from diverse sources, can be transferred within many environmental compartments and end up in the soil-plant system through the uptake and the accumulation of these metals in that system. Some soil active components play a vital role in controlling heavy metals activity such as soil organic components, minerals and microorganisms. Each component has a special contribution towards soil-plant system contamination by cadmium and lead. This sort of contamination alters the food web and human health through several routes, as shown in Figure 3. The interaction of those active components with heavy metals should be further investigated to show the possibilities of reducing such pollution. As stated by [76], the impacts of heavy metals can be reduced in mine soils that have higher concentrations of iron and manganese oxides, humified organic matter, and clay minerals, particularly chlorite, gibbsite, and goethite.

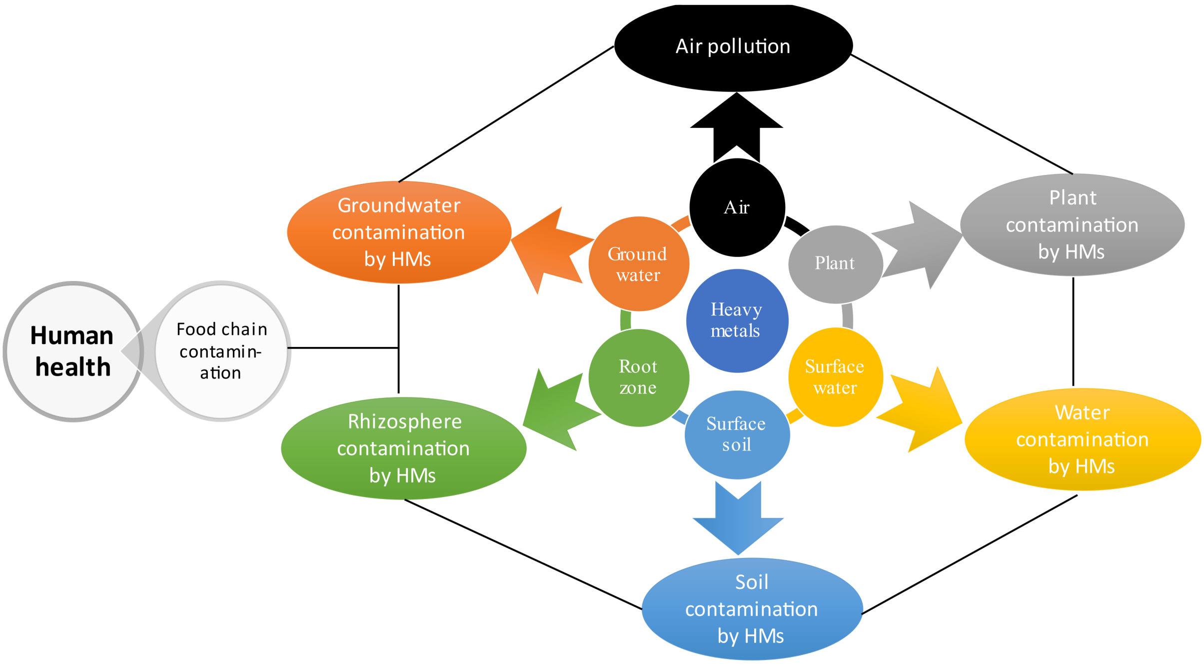

Figure 3. The possible environmental components affected by heavy metals that can introduce cadmium/lead to the food chain, affecting human health.

Via the process of sorption and migration, cadmium and lead can be transported, and this process is guided by several properties (soil properties, climate conditions, plant type). Cadmium and lead have a strong connection to the soil properties that allow them to highly concentrated in various systems. Numerous studies have shown the correlation of cadmium and lead with soil properties as presented in Figure 4, such as pH, organic matter, and exchangeable cations [20,54,56,60,66,73].

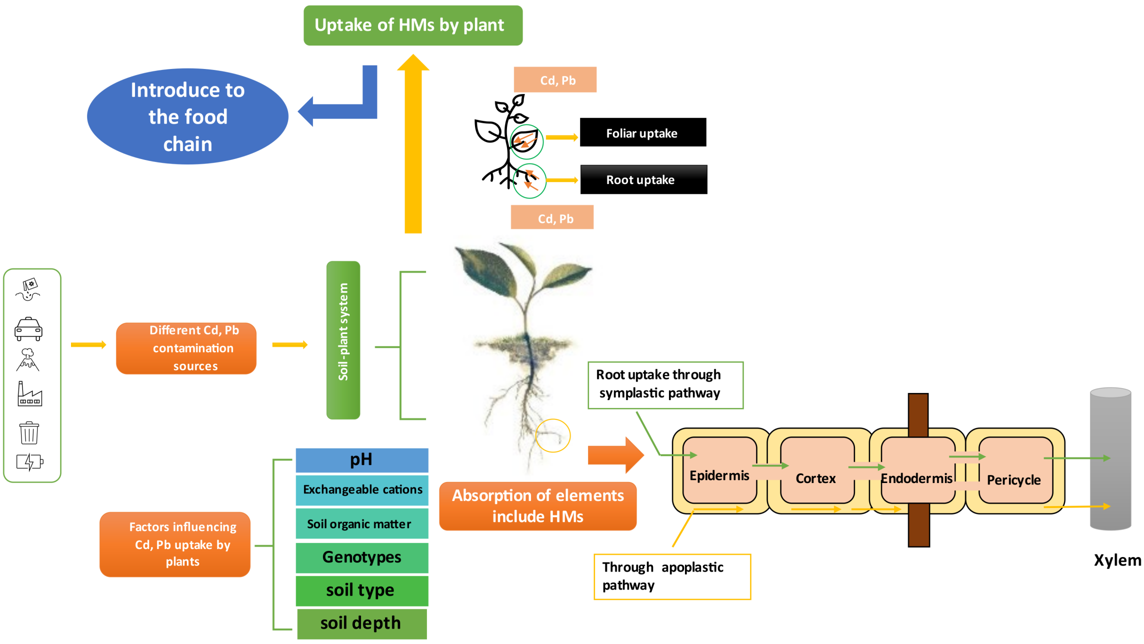

Figure 4. Cadmium and lead contamination pathways towards soil-plant system under the influence of different factors (apoplastic pathway through cell wall, symplastic through cytoplasm).

Cadmium and lead were detected in high levels in soil from the Langat water catchment area because lead has a positive relationship with exchangeable cations and a negative relationship with organic matter. In contrast, cadmium has a positive relationship with organic matter and a negative relationship with exchangeable cations [20,56,60]. Heavy metals are more soluble in acidic soils with high organic matter and these factors may assist the metal enrichment in soil and create a suitable environment for the mobility of the metals [56]. Further, soil type and depth have an extensive role in the metal availability in soil as well, where clay and surface soils contain more metals than soils with a sand texture or soil at greater depth [26,56,73]. According to [26], heavy metal concentration decreases with soil depth and with physical dilution depth, distance, and increased mobility limits. On the other hand, roots play a vital role in the uptake and translocation of heavy metals. Plant roots generally have the greatest concentrations of metals compared to other plant tissues; and fruits usually contain the lowest levels. The metals' entry into the plant is subject to the anatomy and environmental adaptability of this plant. Normally, stomata and cuticles are responsible for the uptake of heavy metals from the soil [77]. Therefore, the accumulation of cadmium and lead depends on plant species, soil conditions, and chemical species [78].

Plants taking up essential nutrients such as nitrogen, phosphorus and potassium at the same time collect undesirable metals such as lead and cadmium. By diffusion through plasma membranes (PM), the metals can enter the plant cell (PM) via endocytosis and due to the activity of the PM's special metal conveyors [79] and consequently metals are introduced into the food chain. Cadmium may end up in the human body through absorption into leaflets and subsequent transport across the plants [60].

6. Health Effects of Cadmium and Lead Exposure

Cadmium and lead toxicity is a ubiquitous problem as their health effects are countless and can even lead to mortality of the exposed individuals. Their route of exposure can be through ingestion, inhalation, or dermal absorption. However, dietary exposure is the main pathway to accumulation in the human body accumulation. Through the consumption of contaminated food such as vegetables and fruits, which supply most of the important nutritional elements for the human body, toxic metals may enter the body and cause chronic difficulties in the long term after the consumption of even low doses of toxic elements such as cadmium and lead.

In the past investigations concerning the dietary intake of cadmium and lead, various analytical methods were used to determine their concentration levels in popular foodstuffs, as listed in Table 5. Vegetables and rice grains were detected to be the main contributors to cadmium and lead exposure, and this is due to their high ability to accumulate those two elements in their tissues as mentioned in the previous sections.

Table 5. Dietary intake of cadmium and lead and their main food contributors from previous studies (2015–2021).

Location	Trace Element	Analytical Method	Main Food Contributor to TE Exposure	Dietary Daily Intake (µg/kg/BW/day)	References
Italy	Cadmium	ICP-MS (7500 Agilent)	Cereals, vegetables	0.0714 µg/kg BW/day	[80]
China	Cadmium	ICP-MS	Rice, vegetables	2.37–6.93 µg/kg BW/day	[81]
China	Cadmium	(ICP-MS, Perkin Elmer, Waltham, MA, USA)	Rice, vegetables	Adult 3.4–6.5 Children 4.1–7.9 µg/kg BW/day	[82]
China	Cadmium	GFAAS	Vegetables (loofah, carrot, radish, bok choy, cabbage, celery, Chinese cabbage, lettuce, mustard)	100 µg/BW kg/day	[83]
China	Lead	ICP-MS	Vegetables and their products	0.0938–0.1210 µg/kg bw/day/	[84]

Table 5. *Cont.*

Location	Trace Element	Analytical Method	Main Food Contributor to TE Exposure	Dietary Daily Intake (µg/kg/BW/day)	References
China	Cadmium	GFAAS	Rice leafy vegetables and wheat flour	0.17 µg/kg bw/day	[85]
China	Lead Cadmium	ICP-MS	Vegetables (stem, leafy, and fruit vegetables)	0.052 µg/kg bw/day 0.038 µg/kg bw/day	[86]
China	Lead	GFAAS (Thermo SOLAAR model iCE3000)	Marketed vegetables	0.459 µg/kg bw/day	[87]
China	Lead Cadmium	AAS (AANALYST800, Perkin-Elmer)	Leafy vegetables	0.219 ug/kg/day 0.013 ug/kg/day	[23]

In addition, cadmium and lead can be transported to the human body via inhalation of urban soils, because soil can also be easily lifted into the air by wind or human feet, producing airborne particles that can pose a potential health risk through inhalation [88]. Cadmium and lead are classified as hazardous elements to human health, as noted earlier. The International Agency for Research Cancer has categorised Cd as a human carcinogen (IARC) [89]. In Malaysia, lead was the leading health concern followed by cadmium [62]. The potential health risk can be estimated and predicted by calculating the Targeted Hazard Quotient (THQ), Hazard Index (HI), and Hazard Quotient (HQ) after conducting a survey using a questionnaire format for the exposed individuals. Several studies have used to calculate THQ, HI, and HQ to better investigate the potential health risk of these elements [for instance, a study conducted on the bitter gourd indicated that in both adults and children, THQ was less than 1.00, which suggests that lead, through the use of three farms' bitter gourds, does not provide a non-carcinogenic danger] [72] (Yap et al. 2019). Research [71] into levels of lead in pak choi, amaranth, and caisim indicated a low THQ < 1 value meaning that there was little or no non-carcinogenic risk posed by the consumption of leafy vegetables; similarly, the findings in [90] show no non-carcinogenic dangers of metals from Indian mustard intake where both adults and children have a THQ < 1.0. However, these risk estimations still indicate just the possible doses that can have a carcinogenic or a non-carcinogenic effect on the human body. The after-exposure effects are the most atrocious when the toxicity in the human body starts disrupting nervous, cardiovascular, gastrointestinal and respiratory systems due to high lead and cadmium exposure.

Cadmium has been linked to many types of cancer. Since cadmium could enter the body through the two major pathways of ingestion and inhalation as stated in [91], workers of many professions were exposed to a high degree of cadmium in inhalation of dust and fumes, and incidents of dust in contaminated hands, cigarettes and food, in particular those working in alloys and batteries, and the non-ferrous smelting and refining of metals. Cadmium targets various organs, namely the kidney, lungs, and bones on account of its persistence and non-degradable properties. In addition, cadmium half-life for elimination from the human body is predicted to be as high as 30 years [92], and in the meantime cadmium can provoke damage to many organs, as shown in Figure 5. Cadmium is known as a bones disrupter due to its ability to cause a disorder in the absorption of the essential nutrients in agreement with the finding in [93] that cadmium impedes the metabolism of magnesium, zinc, calcium, iron, and copper, decreasing proper vitamin D activation and phosphate absorption in bones. Calcium, magnesium, zinc, and iron are recognized as vital elements for bone strength, and Vitamin D helps to fix calcium and other nutrients in the bones; their absence in bones may cause bone weakness, augmenting the risk of bone fracture and osteoporosis. Moreover, cadmium can be transported to the liver. It can be absorbed from the lung or gastrointestinal tract, and sequestered after binding to metallothioneins (MTs) [92]. This can give rise to free radicals (ROS) risk as oxidative stress is generated in live cells to detoxify reactive intermediates or to repair damage resulting from the imbalance between reactive oxygen species (free radicals) and the formation of antioxidants [94,95]. Research on cadmium exposure and its effects are in the advanced stage; many detection and tracking technologies have been developed to measure its concentration levels and better understand its pathways and this enables the concerned medicine toxicologists to diagnose and treat the affected people.

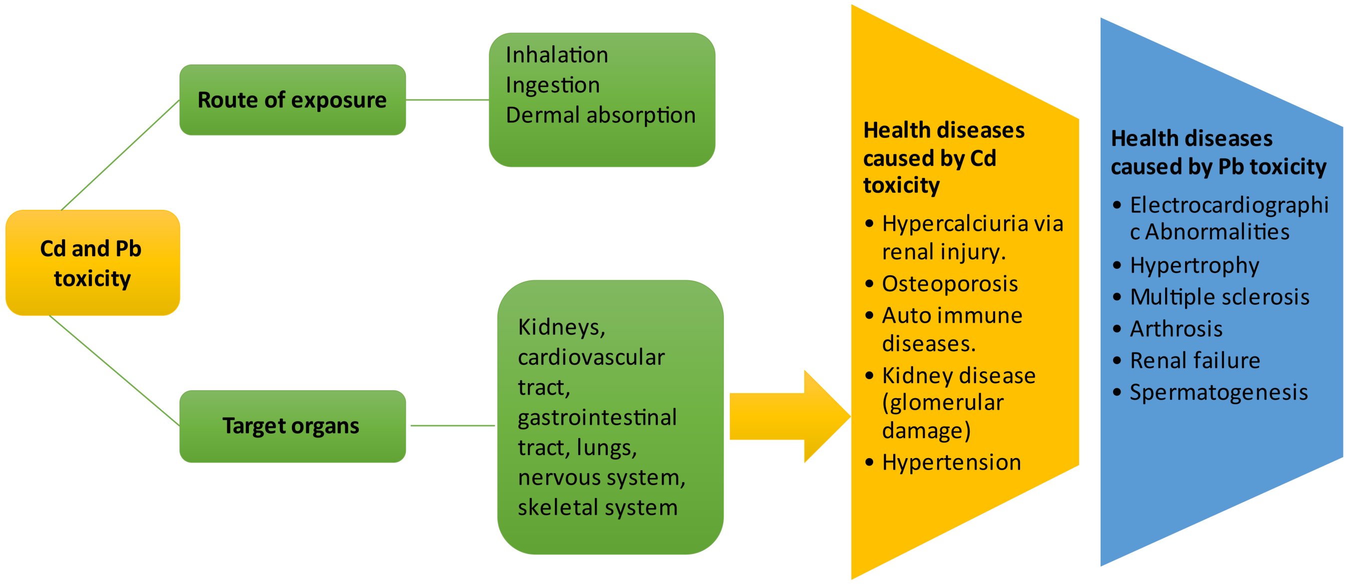

Figure 5. Pathways of lead and cadmium and their impact on human health.

Furthermore, lead was reported in various studies to cause health diseases as much as cadmium. It can be taken up into the human body through inhalation, ingestion, or dermal absorption and targets the respiratory and gastrointestinal tracts, nervous system, kidney and skin [96] as is shown in Figure 5. This can increase the inflammatory mediators, tooth loss, hypertension, cardiovascular disease and kidney weights [96]. Lead's capacity to replace other bivalent cations such as Ca^{2+}, Mg^{2+}, Fe^{2+} and monovalent cations such as Na^{+} is of great interest because this ionic mechanism of lead toxicity can easily disturb the biological processes such as cellular adherence, intracellular and intercellular communication, protein folding, maturation, apoptosis, the transit of ions, regulating enzymes and releasing neurotransmitters [95,96].

7. The Remediation and Mitigation Techniques and Strategies

Since cadmium and lead accumulation can possibly produce countless effects on soil, plant and human health, a profound remediation of these elements is required. Various technologies such as soil washing, soil amendment, phytoremediation, electrokinetic remediation, and nanotechnology have been proposed to remove cadmium and lead from the soil. The type of metal is one of the key factors for a successful remediation along with many other factors namely soil type, depth of contaminated soil, and type of agents used.

Soil washing is an ex-situ removal technology based on the use of washing solution and a mechanical friction to remove cadmium/lead from soil or to reduce their levels. Leaching agents/surfactants are usually used for the desorption of the contaminants; additionally, they have been proven to show high effectiveness in heavy metals remediation with low cost [97–101]. Based on the literature, soil washing showed high efficiency in cadmium/lead removal, and it can be considered as a prospective remediation technique for these toxic elements [102,103]. On the other hand, the limitations of soil washing, as mentioned in Table 6, can influence its effectiveness; soil properties could be destroyed after the washing process and require a long recovery period before the soil can be used for agricultural purposes.

Phytoremediation is a green technology that uses plants to reduce, remove and eliminate the toxic metals from soil [104,105]. The remediation process depends on the plant species and the type of contaminants in general. For instance, a study on two medicinal plants has shown their ability to accumulate Pb; *Centella asiatica* and *Orthosiphon stamineus* have various heavy metals removal methods [106]. *O. stamineus'* roots showed a higher concentration of Pb, while Pb was more concentrated in *C. asiatica's* leaves. Therefore, their potential as phytoremediation agents must be further developed [106]. In addition, the plants selected for phytoremediation purposes must be suitable and able to uptake, accumulate, and degrade the contaminants without much impact on other characteristics such as the growth rate, biomass, and root structure [107]. Numerous studies have investigated the ability of many plants to accumulate added cadmium and lead. One study [108] appraised the phytoremediation capability of *Ipomoea aquatica* and *Spinacia oleracea* to eradicate cadmium and lead from contaminated soil. The growth rate was reduced and this was explained by the transplantation of the plants from the clean soil to the contaminated soil [108]. Plants took time to adapt to the new environment and this could be observed in their decreased growth rate and changes in colour, number of the leaves and roots, etc. In the same research, the results showed that the roots in polluted soil were less short than those of plants cultivated in unpolluted soils once the plants have been harvested. The high concentration of cadmium might induce this behaviour [108], since short roots may not absorb required nutrients from the polluted soil in contrast to the longer roots; this may be an adaptation mechanism of the plants. *I. aquatica* is found to be more proficient and equipped to remove 29.00% of cadmium and 27.72% of lead from the soil, due to its roots being deeper and more extensively spread, which facilitates and enhances metal absorption [108]. *S. oleracea* reduced soil lead by 25.91% and soil cadmium by 25.27% [108]; this is probably attributable to the morphology of the plants. Differently, a research study has used *Imperata cylindrica* to eliminate lead and cadmium from leachate [109], as leachate is known to be rich in harmful contaminants, notably cadmium and lead. *Imperata cylindrica* was efficiently able to remove 56.3% of lead and 16.2% of cadmium and accumulate them in the roots in agreement with [109]. The study showed a remarkable transformation of the plant roots whereby some new hairy roots and fresh shoots were developed; moreover, the color of the leaves started to change at day 16 during the experiment and this wa most likely caused by the adaptation of plants to heavy metals in the raw concentrated leachate. Similar to *Ipomoea aquatica* and *Spinacia oleracea* changes because of transplantation [108], *Imperata cylindrica* has experienced some changes by reason of transplantation from normal soil into liquid and thin medium [109]. Another plant experiment was reported in [104], to establish the ability of Vetiver grass, *Vetiveria zizanioides* (Linn.) Nash, in removal of heavy metal from contaminated soil. This study reported that *Vetiveria zizanioides* has a rapid growth, large roots and high depth system and it can be considered as an efficient phytostabilizer of cadmium and lead due to the relatively higher accumulation of heavy metals in its roots [104] compatible with the recommendations in [107]. Thus, many plants are found to be effective phytoremediators of cadmium/lead. This suggests the efficiency of phytoremediation as a removal method with several advantages as well as some limitations, as shown in Table 6.

The waste generated from the remediation process contains high amounts of cadmium and lead. The post remediation phase is very important as the produced waste must be well controlled in order to avoid further pollution. The United States Environmental Protection Agency (EPA) provides comprehensive guidance for remediative waste management under the Resource Conservation and Recovery Act (RCRA).

Table 6. Summary of different soil amendment technologies to remove cadmium/lead.

Contaminant	Reagent/Plant Species Used	Main Finding and Summary	Advantages	Limitations	Reference
Cadmium from agricultural soil	fulvic acid-aided hydroxyapatite nanofluid. Nanotechnology	The findings show that nHAP nanofluid has a high potential for removing cadmium from polluted soils, and that organic acids play a critical role in assisting the process provided proper subsurface drainage and leachate collecting systems are present on-site.	Environment friendly. cost-effective nanosuspension.	Doubt in separation of the nanomaterials from soil particles.	[110]
Lead from agricultural soil	biodegradable chelators (N, N-dicarboxymethyl glutamic acid tetrasodium salt (GLDA), ascorbic acid and citric acid). Soil washing	Pb removal might be considerably improved by combining GLDA with CA (citric acid) and ASC (ascorbic acid). The findings of this study imply that a GLDA-ASC combination might be a viable alternative for Pb elimination.	Permanent results Low-cost method Does not take a long time The used chelating agents are biodegradable. GLDA has a low ecological footprint. Applicable for soils with high HMs contamination rates.	Lab based experiment.	[111]
Cadmium	*Sorghum bicolor* Phytoremediation	Cadmium at low levels might enhance the development of *S. bicolor*, while *S. bicolor* could not accumulate cadmium at high levels. Many variables impact cadmium absorption by plants, including soil quality, plant species, soil microorganisms, and cadmium species in soil. Under cadmium stress, a high level of microbial diversity was discovered, which influenced plant growth.	High biomass yield and rapid growth. High tolerance to adverse environment and ability to produce bioenergy. Effective, economic, and environment friendly method	The *S. bicolor* cannot accumulate Cd in high levels. Lab-based experiment.	[112]
Cadmium	Two ecotypes of *Bidens pilosa* L. Phytoextraction	The net photosynthetic rate, transpiration rate, SOD activity, and extractable Cd content were all greater after HAE (Hanzhong ecotype of *Bidens pilosa* L.) treatment than after SHE (Shenyang ecotype of *Bidens pilosa* L.) treatment. These characteristics may be partly responsible for HAE's increased cadmium accumulation from soil, indicating a genetic foundation for this hyperaccumulator's enhanced tolerance and accumulation.	Cost-effective and environment friendly technology.	Small scale only.	[113]

Table 6. *Cont.*

Contaminant	Reagent/Plant Species Used	Main Finding and Summary	Advantages	Limitations	Reference
Lead	Ethylene-diamine-teraacetic acid disodium salt (EDTA-2Na) combined with diluted deep eutectic solvent (DES). Soil washing	The treated soil showed no corrosion or mineralogical alterations because of the chemical washing. The washing process had no discernible effect on the mineral phase of the soil or the functional groups of CEEN. As a result, this method may be used to treat lead-contaminated soil.	Rapid and efficient remediation method. Environmentally friendly, non-toxic, and affordable.	High viscosity of the reagents makes recycling the soil after remediation challenging, and a dilution of the reagents is required.	[114]
Cadmium	*Amaranthus hypochondriacus* L. Phytoremediation	The level of soil cadmium contamination and soil CEC both influenced grain amaranth growth and cadmium accumulation. The results indicated that low soil CEC is a significant limiting factor impacting the phytoremediation efficacy of grain amaranth.	Cost-effective and eco-friendly method.	Small-scale.	[115]
Lead and cadmium	Extracted water from *Fagopyrum esculentum* and *Fordiophyton faberi* Soil washing	The study showed the capacity of plant solutions in soil washing, and results revealed the ability of the prepared solutions to extract lead and cadmium from soil, where *F. esculentum* has shown higher extraction levels than *F. faberi.*	When compared to EDTA, plant washing agents perform better in terms of lowering metal hazards and mitigating the impact of washing on soil chemical characteristics.	Small-scale only.	[116]
Cadmium	Biosurfactant: rhamnolipid (RL) and saponin (SP) Soil amendment	The findings indicate that using biosurfactants can help in soil remediation by corn where the results reveal that raising the biosurfactant concentration from 1 to 5 mmol kg^{-1} influenced the amount of Cd leached out of the soil samples.	It does not need a disposal site. The biosurfactants can increase the corn biomass. The produced biomass can be used as bioenergy.	It requires a suitable place/plant.	[117]
Lead	Biochar (magnetic biochar MBC) Soil amendment	Results revealed that MBC can efficiently remediate lead contaminated soils. The key parameters influencing Pb removal effectiveness from soils were Pb sorption capacity by magnetic biochar, magnetic biochar recovery efficiency, and chemical forms of lead in soils.	Feasible approach for lead contaminated soils.	Soil type and magnetic biochar can influence the efficiency of the remediation.	[118]
Lead and Cadmium	Adsorbent (bentonite) Soil immobilization	Bentonite additions lowered the exchangeable proportion of cadmium and lead, the majority of which was transformed into inaccessible forms. Cadmium and lead translocation from soil to aerial portions of *Oryza sativa* L. was inhibited by bentonite treatments.	Short cycle, cost-effective. Easy to implement. High efficiency.	The immobilised heavy metals can still be present in soils and may be released back into water if soil conditions alter.	[119]

Table 6. *Cont.*

Contaminant	Reagent/Plant Species Used	Main Finding and Summary	Advantages	Limitations	Reference
Lead and cadmium	Newly modified material fly ash (NA), zeolite (ZE), and fly ash (FA). Soil amendment	The use of NA and ZE lowered the concentration of accessible metal ions and reduced cadmium/lead accumulation and capability for sequestration, resulting in a decrease in the acid-exchangeable fraction of cadmium/lead and an increase in the oxidizable and residual fractions.	Can be applicable in field. Sustainable treatment.	Secondary pollution may be caused. Side effects of the fly ash. Cannot be used to remediate a mixed heavy metal pollution.	[120]
Lead and cadmium	Thiol-modified rice straw biochar Soil immobilization	These findings imply that RS (rice straw) might be a viable remediation solution for heavy metal pollution in water and soil.	Effective method for cadmium and lead remediation.	It may influence the microbial activity. Difficult to separate from soil after treatment.	[121]
Cadmium	Non-magnetic silicate bonded biochar (SBC) and magnetic silicate bonded biochar (MSBC) Soil amendment	The biochar substance has magnetic characteristics and can be separated by magnetic field force, making it ideal for recycling and secondary use.	The ability to reduce cadmium bioavailability in soil. Good adsorption and passivation performance. The treated soil with silicate bonded biochar helps in the plant growth.	It requires more than one cycle. In-situ passivation cannot completely remove Cd from soil.	[122]
Cadmium	Composite (biochar-supported iron phosphate nanoparticles, sodium carboxymethyl cellulose) Soil immobilization	The findings of consecutive extraction techniques revealed that the decrease in Cd bioavailability in soils was caused by the change of more conveniently extractable Cd to the least accessible form. Experiments on plant development showed that the composite may prevent Cd absorption to both the belowground and above-ground parts of the plant.	The method can immobilize cadmium in soil by reducing its bio accessibility. Short term method. The composite had the ability to successfully change a more bioavailable cadmium speciation into a significantly less bioavailable speciation. It helps in promoting the plant growth.	It may influence the soil fertility. It needs more field investigations. Secondary pollution. Chemical immobilisation might not reduce heavy metal concentrations in the long-term.	[123]
Cadmium	Sunflower (*Helianthus annuus* L.) + chelating agents (citric acid (CA), oxalic acid (OA) and ethylenediamine disuccinate (EDDS). Phytoremediation	According to the findings, chelating chemicals exacerbated the negative effects of Cd combined stress on the sunflower by lowering plant biomass and limiting photosynthesis, while boosting sunflowers' ability to absorb and transport Cd to variable degrees.	Phytoremediation potential can be increased by adding chelating agents (chelating agents can stimulate the metals uptake by plants). Cost-effective and eco-friendly method. High biodegradability of the chelating agents. Sunflower has high bioaccumulation capacity, strong stress tolerance and short growth cycle.	Enhanced plant stress, decreasing biomass, inhibiting photosynthesis, and increasing malondialdehyde and H_2O_2 levels. Cannot be used in highly contaminated regions.	[124]
Cadmium	Electrokinetic remediation	The cross-impact of factors affects Cd migration in soil, and effective in-situ removal of Cd from soil may be obtained by adjusting parameters appropriately.	Minimal soil disruption. Suitable for low permeability soil. High removal efficiency.	The degree of solubilization and desorption of the metal may impact the removal efficiency.	[125]

Table 6. *Cont.*

Contaminant	Reagent/Plant Species Used	Main Finding and Summary	Advantages	Limitations	Reference
Lead	Ammonium-based deep eutectic solvents with saponin (DESs) Soil washing	This study indicates the appropriateness of employing DESs in conjunction with saponin for soil washing. The DESs and saponin worked better when used together rather than separately, showing a synergistic behaviour in which they both contribute to Pb2+ removal from soil.	Biodegradable and low-cost solvents. Sustainable technique.	Need further investigations.	[126]
Lead	*Helianthus annuus* L. Phytoextraction	The study revealed the ability of five varieties of *Helianthus annuus* L. to extract Pb from contaminated soil. The potential of Phule Bhaskar to accumulate Pb is larger than that of the other varieties. (it took 60 days)	Green technology, cost-effective.	It requires a long time for plant growth and metals uptake. Long life cycle. Low removal efficiency.	[127]
Cadmium	Cation exchange resin (CER), biochar (BC), and steel slag (SS). Soil amendment	The results illustrated that the used device with the chosen amendments (CER, BC, SS) could eliminate Cd in soil, and reduce Cd levels in rice grain as well.	Easy implementation. Cost-effective. Reusable in-situ technique. Stimulates rice development. Improves crop photosynthesis. Minimizes oxidative damage. Diversifies the microbial population. Lower rice grain HRI.		[128]
Lead and cadmium	Statice (*Limonium sinuatum* (L.) *Mill*) Phytostabilization	The study revealed that mycorrhizal plants produced more biomass at the highest Cd or Pb doses. Thus, Statice plant is a viable alternative for revegetating lead or cadmium-polluted industrial sites or urban landscapes, especially following mycorrhizal inoculation.	Plant roots have higher capability to accumulate the metals than other plant parts.	Pb and Cd could inhibit the plant growth and lead to metal stress.	[129]

8. Conclusions

In this paper the effects of both cadmium and lead have been largely discussed, where their concentrations were found to be higher in both soil (industrial, agricultural, landfills) and plants (rice grain, leafy vegetables, medicinal plants, fruits) in different countries across the world. Their fate and distribution in the environment are influenced by several factors such as soil properties, plant structure and capability, and climate conditions. Cadmium and lead toxicity cause countless health issues such as kidney damage, lung cancer, and nervous system diseases. Nevertheless, there are a few preventive measures and remedies that may help reduce the concentrations of cadmium and lead in the environment such as phytoremediation. These measures can be realized on a small scale and reduce or even eliminate heavy metal presence in contaminated soil. Full-scale application of these cost-effective and ecofriendly approaches needs more investigation to further develop the methods. However, heavy metal contamination is still considered as a hidden danger to food safety and soil quality, requiring further monitoring and assessment.

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