Review Article

Sustainable remediation solution for heavy metal contaminated soils of Pakistan: A review

Nusrat Ehsan^{1,2*}, Khalid Mahmood Qamar², Qamar uz Zaman¹, Waqas Ahmed¹, Ambreen Aslam¹ and Faisal Mehmood³

1. Department of Environmental Sciences, the University of Lahore, Lahore-Pakistan

2. Department of Environmental Management, National College of Business Administration and Economics, Lahore-Pakistan

3. Department of chemistry, the University of Lahore, Lahore-Pakistan

*Corresponding author's email: nusrat.ehsan@envs.uol.edu.pk

Citation

Nusrat Ehsan, Khalid Mahmood Qamar, Qamar uz Zaman, Waqas Ahmed, Ambreen Aslam and Faisal Mehmood. Sustainable remediation solution for heavy metal contaminated soils of Pakistan; A review. Pure and Applied Biology. Vol. 10, Issue 2, pp474-491. <http://dx.doi.org/10.19045/bspab.2021.100051>

Received: 22/05/2020

Revised: 05/08/2020

Accepted: 05/10/2020

Online First: 27/10/2020

Abstract

The heavy metals are recognized as major threat to the agricultural land. Most of these heavy metals enter in soil due to anthropogenic sources including rapid urbanization, industrialization, excessive use of pesticides, herbicides and fertilizers, mining and smelting activities and electronic wastes etc. The complexity of soil-heavy metal interaction is also increased due to inefficient sewage systems, use of industrial water for irrigation purposes without proper treatment. The translocation of H.M.s from Soil to the vegetative parts and accumulation in vegetative parts of the plants and humans has become an emerging threat to human health. Several physical, chemical, and biological techniques are being practiced for the remediation of heavy metals contaminated soils in Pakistan. However, in developing countries like Pakistan, high costs of equipment, energy supply, operation and maintenance limits their applicability and sustainability. On the other hand, Phytoremediation is a cost-effective technique which relies on solar energy to boost up the process with minimum technical, operational and maintenance cost. Finally, the disposal of contaminated plants used in Phytoremediation can be achieved through different procedures like incineration, compacting, pyrolysis, leaching depending upon the availability of resources and type of plants. The cost-benefit analysis reveals that cost highly varies depending upon a number of factors and the minimum estimated cost ranging from \$10-35. The hyperaccumulator plants provide a reasonable solution for heavy metal contaminated lands with less cost and limitations as compared to the other techniques.

Keywords: Bioaccumulation; Contamination; Cost-benefit analysis; Phytoremediation; Pollution

Introduction

The soil is a complex mixture of chemical compounds formed by the erosion of rocks [1, 2]. It acts as a large sink for contaminants and a natural buffer that controls the transport of contaminants and

other substances to the hydrosphere, living organisms, and atmosphere. However, the prominent central role of Soil is its productivity, which is essential for humans to survive on the earth, hence, the protection and management of soils for

agricultural or ecological functions are the responsibility of humans [3].

The composition of Soil is an essential factor from the agricultural point of view as the plants take nutrients from Soil. However, certain chemicals like pesticides, fertilizers, chlorinated solvents and heavy metals at a certain level contaminate the natural composition of Soil [4]. The increasing rate of heavy metals such as lead (Pb), Arsenic (As), cadmium (Cd), nickel (Ni), copper (Cu), mercury (Hg) and chromium (Cr) in Soil has been recognized as a worldwide issue due to their chronic effects on human and ecosystem [5]. Heavy metals in Soil are of major concern due to their long-term persistence as a pollutant, low solubility, and their mutagenic and carcinogenic nature [6]. Their cumulative effects have long-term impacts on the environment; also, these can bioaccumulate in vegetative parts of the plants and enter the human bodies through the food chain [4, 7]. The bioaccumulation of heavy metal may cause of several diseases and congenital disabilities [4, 8-11].

According to the recent findings of Pakistan Economical Survey 2016-2017 [12], the agriculture-based Gross Domestic Product (G.D.P.) during 2016-2017 was 19.5%, which has declined 33.5% since 1949 which was 53%. Agriculture is the main source of livelihood (43.5%) of the rural population [13]. However, due to an increase in population, agricultural practices have been forced to increase production. The quality of Soil in Pakistan is being degraded due to a number of natural and anthropogenic activities. The use of sewage and wastewater for irrigation purposes has increased the threat of heavy metal contamination in agricultural fields, especially in developing countries like Pakistan [14].

The analysis of soil quality and removal of contaminants from the agricultural soils is required before production of crops and to avoid bioaccumulation of contaminants from plants and humans. Several soil management or remediation techniques are

used to reduce the availability and transportation of heavy metals in soils. These techniques of heavy metal polluted soils include physical remediation, chemical remediation, bioremediation and agro-ecological engineering procedures [4].

One efficient and potential method of soil decontamination/ remediation is Phytoremediation which involves the use of plants to uptake, sequester and detoxify contaminants. This method has different types such as phytoextraction, rhizofiltration, phytovolatilization and phytostabilization. The major advantages of Phytoremediation over other techniques are a preservation of natural soil attributes, cost-effectiveness, and dependence on solar power to boost up the remediation.

Hence, the current review aims to discuss the risks associated with heavy metal contamination in agricultural land of Pakistan and also suggests Phytoremediation as an economically and technically feasible and sustainable solution to resolve this issue of soil contamination.

Major contaminants in soil

The presence of nutrients in Soil does not necessarily indicate the contamination of Soil as the natural composition of Soil varies from space and time [15]. The addition of fertilizers and various chemicals which may enter the Soil due to irrigation from contaminated water, industrial effluents and use of fertilizers decreases the soil quality, characteristics and performance. The contamination of Soil due to heavy metals have a relatively deleterious impact as these metals are persistent [3, 16, 17]. The sources of heavy metals in soils are classified as natural and anthropogenic sources.

Natural sources

Heavy metals enter the environment through some natural sources such as weathering of earth crust, mining, soil erosion, volcanic eruption etc. [18, 19]. The accumulation of these metals in Soil has a worse impact on environment and soil-

dwelling organisms. Another major source of H.M.s in Soil includes mafic and ultra-mafic rocks. The rocks are quite rich in H.M.s such as Ni and Cr, Mg, and As [20].

Anthropogenic sources

Variety of anthropogenic sources including industrial effluents, improper solid waste and sludge disposal, vehicular exhaust, pesticides and insecticides used in agricultural fields, irrigation of crops by sewage water, improper disposal of batteries and other E-waste etc. [21-25]. Pallavi and Rama [26] quoted that several heavy metals have increased intensely in the ecosystem by human activities. In many areas, the industrial wastewater enriched in heavy metals is discharged in rivers and streams without any treatment. When this water is used for irrigation of crops, severe damage to Soil and ultimately to crops occurs. Tilling activities, grinding and concentrating ores are also the main sources of heavy metals contamination of Soil from mining. (Fig. 1) represents the anthropogenic sources of different heavy metals in Soil.

Permissible limit of H.M.S. indifferent mediums

Problem of heavy metal pollution

In Pakistan, the problem of H.M. pollution is very severe and is becoming economic and planning concern [27]. Effects of toxicity caused by heavy metals have been reported by many researchers especially in developing countries [28-30].

The major sources of heavy metal contamination in Pakistan are mentioned below:

Tanneries and leather processing industries

Leather products and tanneries are major industries in Pakistan, contributing 4% in GDP. Some major cities like Lahore and Kasur have ancient tradition in tanning and processing of animal hides. The tanning process in Kasur as well as in Karachi is a severe environmental problem as it produces large amount of Cr- rich effluent and solid waste. Chromium is a very toxic heavy metal and is a big source of borne

environmental cancer [31]. Mussarat et al., [32] found that the concentration of Zinc (Zn), Pb and Ni in effluents of Faisalabad industries were mostly higher than the permissible critical limits as defined by Punjab Environmental Quality Standards (P.E.Q.s) and Food and Agriculture Organization(F.A.O.).

Sewage and municipal waste

In many cities of Pakistan like Karachi, Lahore, Faisalabad, the sewage and municipal waste is major source of irrigation for crops. Wastewater dumping in the freshwater bodies (rivers) without proper treatment is a common practice. This water is used for irrigation purpose in agricultural fields. The H.M.s are taken up by the roots of plants and they accumulate in various parts of plants and hence they may enter the food chain. A research conducted in Faisalabad district Pakistan indicated that the use of sewage and contaminated water in agriculture had high metal content, Chemical Oxygen Demand (C.O.D.) and electrical conductivity [33]. The heavy metals like Cd, Cr, Ni, and Cu were in higher limits in the soil samples of Rawalpindi due to the use of wastewater for irrigation purposes[34]. The extensive use of sewage and industrial effluents results in human health degradation and many clinical problems [27].

Brick kilns and cement production

Some major producers of bricks in Pakistan include Peshawar, Charsadda, Mardan, Bannu, D.I. Khan and Swat districts. The release of heavy metals from brick kilns have an adverse effect on Soil, plants and people residing near brick kilns, especially women and older adults are at greater risk from such pollutants [30]. The concentration of H.M.s, which enters an environment through cement production, contains high concentrations of Zn, Pb, Cr, Ni, Cu and Cd [35].

E-waste

Electronic waste, including computers, televisions and cell phones and batteries, contains high amount of H.M.S. There is no proper disposal procedure for electronic

waste, especially in developing countries. It causes soil contamination and degradation of soil characteristics. The electronic waste is rich in heavy metals like Pb, Cd, Cr, Ni, Hg, tin (Sn) and Zn [36]. According to Han et al., [37] E-waste has the potential to cause health risk, both carcinogenic and non-carcinogenic. The H.M. contamination of water bodies increases due to the discharge of e-waste or leachate seepage from improper waste dumpsites.

Smelting of metals

Smelting of metals is a significant source of Lead (Pb) as it is used in the manufacturing of roof sheets machines, Pb batteries, fuels, and even paints [38, 39].

Permissible limits of major heavy metals

The comparison of H.M.s permissible limits in soil and in canal, ground and waste water is provided in (Table 1). In Pakistan, there are no specific permissible limits for soil and international standards of European Union (EU) are used. However, for canal, ground and wastewater provincial levels are given:

Effects of heavy metal contaminated soil on human health

The concentration of heavy metals above permissible limits have adverse effects on the quality of human life. It not only directly affects humans but also ecosystem that ultimately affects humans. The exposure of heavy metals to humans occurs through three major routes i.e. inhalation (respiration of contaminated air), ingestion (food and water), and dermal (direct contact) of heavy metal concentration with skin [40].

The probability of heavy metals' bad impacts on living organisms depends upon three main factors (i) Dose i.e. concentration that enters in their body (ii) Response i.e. the capacity or immune system to eliminate and (iii) Duration for which the living organism is exposed.

A number of research studies have been conducted to find out the dose and response of H.M.s in human body. The eight most important heavy metals mentioned to be toxic to the humans are listed by

Environmental Protection Agency (E.P.A.), are As, Cd, Cr, Cu, Hg, Ni, Pb, Zn [41]. The H.M.s such as Cd, Cr, Ni and Pb are very poisonous, and their excessive bioaccumulation can cause biochemical changes inside living bodies and produce both chronic and acute health consequences such as renal issues, bone fracture, inhalation problems, asthma, cardiovascular problems and various kinds of cancers [42-44].

Gastrointestinal

A health survey shows that diseases like diarrhea, vomiting, gastroenteritis, dysentery, viral hepatitis, headache, hypertension, irritability, abdominal pain, nerve damage and liver and kidney problems occur due to certain heavy metals [33, 44]. A higher rate of stomach cancer was observed in the community using groundwater with higher chromium levels [45, 46].

Renal system and kidneys

The toxic impacts of consuming Pb, Hg, Cr and Cd contaminated water on human neutrophils are very common [47] and claimed that heavy metals (Cd, Pb and Hg) are endocrine-disrupting compounds. Barbier et al., [48] found that Zn, iron (Fe), and Cu are transported through kidneys to the body resulting in accumulation in various parts. Prolonged exposure to lead contaminants can cause kidney damage and stones. The risk of kidney stones, renal cancer and nephrocalcinosis is also high due to heavy metals [35, 49].

Birth defects

The exposure to H.M.s during pregnancy may cause long term birth defects [50]. Various studies shows that 10 metals i.e. Co, Cs, Sb, Cu, Pb, Mo, Zn, Ti, Rb, Se, and Sr, are present in the blood plasma of umbilical cord [51, 52]. Excessive exposure to Pb can decrease fertility, increase the risk of miscarriages and birth defects [53]. The exposure of Pb in mothers is also responsible for congenital malformations and affects the developing nervous system which may results in

impairment in fetus cognitive abilities [54, 55].

Cancer and tumors

Unlike organic substances, heavy metals are non-biodegradable and therefore accumulate in the body; therefore, they have a greater effect. The accumulation of certain H.M.s like Fe, Cd, Cu, Pb, and cobalt (Co) in human bodies leads towards the risk of cancer [56, 57]. Certain heavy metals are also associated with genomic instability.

Respiratory and occupational diseases

The H.M.s concentrations in the atmosphere may occur due to vehicular exhaust, industrial emissions and erosion of dust. The H.M- contaminated air enters the bodies through inhalation, which enters the bloodstream and may accumulate in bodies. Chromium is highly associated with respiratory diseases, especially when the exposure is occupational. The workers involved in the electroplating process having dermal exposure to chromic acid for even 10 minutes suffer from Nausea, vomiting, abdominal pains, and diarrhea [50].

Translocation of heavy metals

The vegetables and crops are a vital part of the human diet and provide essential nutrients for proper growth. The toxicants from the rhizosphere enter plants through roots in the form of ions. This uptake of heavy metals from roots to the vegetative parts of the plants is referred as translocation. The leafy vegetables are grown in heavy metal contaminated Soil accumulate more heavy metals in their leaves as compared to other plants [33, 58]. The vegetables such as spinach, coriander, lettuce, radish, cabbage and cauliflower are grown in industrial areas in Faisalabad are rich in heavy metals including Pb, Cu, Cr, Zn and Cd [34, 59].

These elements, when they enter the human body, accumulate in the body tissues of living organisms (bioaccumulation) and their concentrations increase as they pass to higher levels (known as biomagnification). The intake of heavy

metal contaminated food is one of the major routes of exposure, which can cause serious health hazards. The exposure of humans to heavy metals can be voluntary, i.e., supplementation or involuntary through intake of contaminated food. These heavy metals enter the bloodstream and can accumulate in body parts. The amount of heavy metals in the bloodstream is related to the bio-accessibility rate.

Remediation of contaminated soil

A number of traditional physical and chemical techniques are used for the treatment of heavy metal contaminated soil. (Table 2) represents the comparison of different remediation techniques along with their advantages and limitations. All of these techniques have their own limitations such as high costs, creation of secondary pollutants and lack of suitability for treating large accidents [60]. The process for selection of remediation technique depends upon a number of factors, including the economic and technical resources, social acceptability and end of life environmental impacts. The schematic diagram for the selection of remediation techniques is provided in (Fig. 2).

Phytoremediation and its types

Phytoremediation is an environmentally friendly and sustainable technique for removal of heavy metal from the Soil by using hyper accumulator plants. This method is practically sounder due to its cost-effectiveness and environmental acceptability [61]. The time frame required for the phytoremediation is comparatively higher as compared to the other techniques like physical and chemical. The time duration required for phytoremediation depends upon many factors including contamination level, type of contamination, soil characteristics as well as the environmental factors. The process of Phytoremediation can be enhanced by the use of certain chelating agents that enhance the ability of plants to extract more heavy metals. The efficiency of using phytoextraction technique depends on the species and characteristics of the plant

species, availability of heavy metals in the Soil, as well as soil characteristics. The characteristics of plants species that are suitable for phytoextraction will be healthier, show tolerance on the heavy metals and accumulate higher concentrations of heavy metals [62]. There are different techniques adopted for Phytoremediation of heavy metals from Soil and rhizosphere. These techniques take the heavy metals from Soil and translocate to the vegetative plants, which can either be extracted (Phytoextraction), biodegraded in plant body (Phytodegradation), volatilized as in case of volatile compounds (Phytovolatilization) or stabilize the concentrations on Soil (Phytostabilization). These techniques, along with their mechanism, is tabulated in (Table 3 & 4).

Bioconcentration and translocation factor

The calculation of bio-concentration factor (B.C.F.) and translocation factor (T.F.) are the key factors to evaluate the feasibility of any plant species for the Phytoremediation of heavy metals. The .C.F.B.C.F. determines the uptake ability of heavy metal from Soil to the plant bodies. The plant species that take higher concentrations of heavy metals are known as hyper-accumulators. The translocation of the metals from roots to vegetative parts of the plants is defined as T.F. (e.g., rhizome, shoots, or leaves and stem) which is regularly used in emergent and submerged plants. Fulekar et al., [21] determined the bioconcentration and translocation factors based equations (Eq. 1, 2).

$$\text{BioconcentrationFactor (BCF)} = \frac{\text{Concentration of Heavy metal in Plant body}}{\text{Concentration of heavy metal in Soil}} \quad (1)$$

$$\text{TranslocationFactor (TF)} = \frac{\text{Concentration of heavy metals in vegetative parts}}{\text{Concentration of heavy metals in roots}} \quad (2)$$

Phytoremediation of heavy metals in Pakistan

A number of researches have been conducted in Pakistan for assessment of plants potential for heavy metal removal from Soil depending upon the availability and climatic factors. The (Table 4) shows the summary of research conducted for plants suitable for Phytoremediation of certain heavy metals in different areas of Pakistan. The remediation and decontamination of heavy metal contaminated Soil is very limited in Pakistan [44]. There are several studies conducted to identify the tolerance of plant species for certain heavy metals and their ability to accumulate heavy metals from contaminated Soil.

Disposal of contaminants plants

The plants used for Phytoremediation contain higher concentration of contaminants such as heavy metals so special treatments and disposal measures are required which may include extraction and recovery of metals, combustion, direct

disposal and composting [63]. The remediation of heavy metal contaminated soil moderates the environmental burden of pollutants. By this technique of Phytoremediation, heavy metals are transported from contaminated land to the plant bodies, which remains an environmental hazard if improperly disposed of [64]. So, appropriate soil remediation and pre-treatment is required before disposal of contaminated plants. Sas-Nowosielska et al. [65] determined that the composting, compaction, pyrolysis, direct disposal, leaching and incineration (combustion and gasification) can be done for the disposal of contaminated plants. The ultimate disposal of contaminated plant remains achieved through the landfill. (Fig. 3) represents the fate of heavy metal contaminated biomass and ultimate disposal achieved through the landfill. The advantages and limitations of each of these post phytoremediation disposal options are tabulated in (Table 5).

Cost-benefit analysis of phytoremediation

The cost estimation for remediation of heavy metals contaminated soil is unique in every case. The studies by Sarma [66] estimated that soil with low contaminations can be cleaned in \$10-35 per ton. According to Gupta et al., [67] removal of contaminants, ex-situ techniques are more costly and may range \$200-600 per ton.

The cost of heavy metal removal from the Soil depends upon a number of factors such as availability of resources, type of technique (in-situ and exsitu), number of irrigations and cost per irrigation, and treatment conditions and plant disposal technique used. The cost estimation for these details is not much discussed in the literature. Moreover, this estimation of cost also varies for developing countries, developed countries, and underdeveloped countries. The cost for field remediation of

soil and batch experiment (greenhouse) also varies.

The comparison of cost estimation for different remediation techniques of heavy metals is illustrated in (Table 6). The soil flushing cost includes the Phytoremediation can be the most cost-effective and sustainable technology for the treatment of heavy metal contaminated soil, especially for developing countries like Pakistan. This technology gains its competitive advantages on conventional treatment methods [63].

As phytoremediation uses no fuel, it is considered to be much cost effective. The study of Zodrow [68], comparisons remediation cost of 500 ppm Pb contaminated soil, and states that plant excavation and final disposal costs \$300,000 per acre, and phytoextraction costs \$110,000 per acre.

Figure 1. Anthropogenic sources of heavy metals in soil

Table 1. Comparison of permissible limits of major heavy metals in soil and water sources (canal, ground, and wastewater)

H.M.s	Permissible limit in Soil (EU) mg/kg	Permissible limit in Canal, Ground & waste water (PEQS) mgL ⁻¹
Arsenic	5	
Cadmium (Cd)	3	0.1
Chromium (Cr)	150	1
Iron (Fe)	5000	8
Lead (Pb)	60	0.5
Mercury	0.5	
Nickel (Ni)	60	0.01
Zinc (Zn)	200	5

Table 2. Comparison of commonly used remediation techniques for heavy metal removal from soil

Remediation Methods	Type	Technique	Application	Limitations	References
In-situ	Physical	Surface capping	High Contamination	- This method is applicable only for remediating small areas (e.g., <2000 m²) - The recent cost ranges from \$20 m⁻² to \$90 m⁻² in the U.S	[52, 69]
		Encapsulation	High Contamination	- This method is applicable only for remediating small areas with shallow and high contamination sites - Applicable for limited compounds - Cost depends upon varies with the depth of contamination and the site geology	[70]
		Electrokinetics	Moderate to High, Fine soil particles	- Suitable only for smaller sized particles and not recommended for large sized soil particles - More suitable for organic compounds	[6, 71, 72]

		Vitrification	Moderate to High, sandy Soil	• Not suitable for clayey and moist Soil • Applicable on shallow depth soils only	
		Mechanical separation	Moderate	• Ex-situ technique so application for the large scale area is a limitation. It is a costly technique • Only useful for highly contaminated Soil • It is mostly used to recover precious metals	[34, 55,]
	Chemical	Soil flushing	Moderate	• Requires more technical and mechanical techniques • Requires high temperature and pre-flushing	[52]
Ex-situ	Physical	Land-filling	High contamination	• Can cause ground water contamination	[6, 52, 72]
		Vitrification	High contamination	• Not suitable for clayey and moist Soil • Applicable on shallow depth soils only • Requires temperature control	
	Chemical	Soil washing	Moderate to high concentration	• Suitable for sandy Soil and not applicable on clayey Soil • High moisture content in Soil may require pretreatment • Additional treatment may be required to remove toxic washing solvent residuals • Difficult to remove organic compounds adsorbed onto clay-size particles	

		Soildification	High contamination	High cost, land and Soillosing environmental qualities	[73]

Figure 2. Schematic diagram for selection of soil remediation technique

Table 3. Types of Phytoremediation and mechanisms

Techniques	Plant Mechanism	References
Phytoextraction	Phytoextraction (also known as phytoaccumulation, phyto-absorption or phytosequestration) is the uptake of H.M.s from contaminated Soil or water by plant roots and their translocation and accumulation in aboveground biomass (A.G.B.) i.e., shoots.	[29, 74],
Phytodegradation	Roots exudates certain enzymes that causes metal precipitation and decreases availability in Soil	[75]
Phytostabilization	Phyto-stabilization decreases the bioavailability and mobility of heavy metals in soils due to their stabilization from off-site transport with the help of plants The metal fixation is accomplished by accumulation of heavy metal in roots and their adsorption, growth and transpiration, the physical stabilization of the soils.	[76, 77]
Phytovolatilization	Phytoevaporation includes uptake and conversion of volatile organic pollutants.	[78]

Table 4. Plant species suitable for phytoremediation of heavy metals in Pakistan

Sr. #	Heavy metals	Plant species	Availability	References
1.	Al, As, Cs, radionuclides, Pb, Zn	<i>Agrostis castellana</i>	Chitral	[79]
2.	As, Mn, Pb, Zn	<i>Agrostis sp.</i>	Northern areas of Pakistan	[80]
3.	Cd, Cs, Ni, Sr, Zn, Cs	<i>Amaranthus retroflexus</i>	Swat, Gilgit, Attock, Murree, Kashmir, Lahore, Quetta	[81]
4.	Cd, Cr, Cu, Ni, Pb, Zn	<i>Brassica juncea</i>	Kaghan, East Kashmir, Islamabad, Quetta, Lahore	[82]
5.	Pb, Cd	<i>Brassica napus</i>	Punjab	[41]
6.	Cr, Zn, Cd, Cu, Ni, Pb	<i>Eichhornia crassipes</i>	Punjab	[83]
7.	Pb, Cr	<i>Zinnia elegance, Vinca rosea</i>	Lahore	[58]
8.	Pb	<i>Festuca ovina</i>	K.P.K, Kashmir	[38]
9.	Al	<i>Hordeum vulgare</i>	From plains upto 4700 in Ladak	[84]
10.	Cd, Zn, Pb, Cr	<i>Lolium perene</i>	Kashmir, Parachinar, Murree, Quetta	[28]
11.	Fe, Cu, Zn, Sr, Pb, Cr, Co, Ni, Cd	<i>Musa paradisiaca</i>	Sindh, Islamabad	[85]
12.	Cd, Cs, Ni, Sr, Zn	<i>Phalaris arundinacea</i>	Punjab, Kashmir, Northern areas of Pakistan	[28]
13.	Ag, Cr, Hg, Se	<i>Salix babylonica</i>	Chitral, Abbottabad, Kashmir, Peshawar	[86]
14.	Cd, Ag, Cr, Hg, Se, Pb, Zn	<i>Salix viminalis</i>	Kishan ganga	[87]
15.	Zn	<i>Silene Vulgaris</i>	Northern areas of Pakistan, Chitral, Naran, Kashmir, K.P.K. Rawalkot	[88]
16.	Cr, Pb, Ni, Zn, Cd	<i>Spirodela polyrhiza</i>	Peshawar, Kashmir, Attock, Rawalakot	[89]
17.	Pb, Zn	<i>Triticum aestivum, typha latifolia</i>	Kurram	[90]
18.	Cs	<i>Zea Mays</i>	Cultivated crop	[91]

Figure 3. Post Phytoremediation options of contaminated plants and ultimate disposal

Table 5. Merits and demerits of disposal techniques for hyper-accumulator plants

Disposal techniques	Merits	Demerits	References
Composting	Volume and water content reduction	It can be implemented under strict monitoring as water solubility of certain metallic compounds will be produced.	[83]
Incineration	This process can cause 99% volume reduction of the contaminated soil. The pollutants concentrate in solid combustion residues (ash, fly ash). The byproduct is easy to transport in controlled, environmentally acceptable manner.	Expensive, requires maintenance and energy to operate.	[65]
Compaction (palletization)	The compacted product is produced by pressure and temperature, which requires technology and	The end products of this method still needs to be treated as hazardous waste.	[92]
Pyrolysis	Since pyrolysis temperatures are lower than in case of other	----	[40, 62]

	thermic processes like combustion or gasification, fast pyrolysis prevents metal volatilization in the reaction zone		
Direct Disposal	Time effective,	Costly, reduction of contaminated biomass is slow, direct disposal may cause environmental problems, main issue is the leachable pollutant content	[43]
Leaching	The leached product (residual biomass matter) can be treated as non-hazardous material	The leachability (i.e. recovery rate) of toxic metals from biomass is generally determined as a function of time and pH value.	[65, 72]

Table 6. Cost assessment of major heavy metal remediation techniques (Source: FRTR Website)

Technique	Major contaminations	Estimated cost per cubic yard (\$)
Soil flushing	inorganic contaminants, VOCs, SVOCs	\$32,320-\$48,729
Soil stabilization	VOCs organics (dioxins and PCBs) metals and radionuclides	\$150 to \$250
Electrokinetic separation	metals and polar organics	\$152
Soil Vapor Extraction	Metals, V.O.C.s	\$300
Soil Washing	mixture of metals, nonvolatile organics, and SVOCs	\$142
Phytoremediation	Heavy metals, organic pollutants, V.O.C.s,	\$112

Conclusion and future research

This review represents the current scenario of heavy metal contamination as increasing threat to the consumers feeding on these agricultural products. The bio-magnification of heavy metals from Soil to the plants and to the human bodies is causing a number of health problems. The comparison of physical, chemical and Phytoremediation techniques represents that both physical and chemical techniques require more costs for energy supply, equipment and machinery, operation and maintenance. Whereas, Phytoremediation is a cost-effective and sustainable solution which involves less technical and operational maintenance. So, this technique can be efficiently adopted in developing countries like Pakistan, where

economic constraints hinder the solutions of environmental problems and associated health impacts. This conclusion is supported by many in-situ and ex-situ experimental designs and cost-benefit analysis. Future research is needed to assess the time required for cleanup of contamination from Soil and the effects of chelating agents on removal of heavy metals from the Soil.

Authors' contributions

Conceived and designed the experiments: KM Qamar, Analyzed the data: N Ehsan & QU Zaman, Contributed materials/ analysis/ tools: W Ahmed, A Aslam & F Mehmood, Wrote the paper: N Ehsan & QU Zaman.

References

1. He C, Zhao Y, Wang F, Oh K, Zhao Z, Wu C & Liu X (2020). Phytoremediation of

- soil heavy metals (Cd and Zn) by castor seedlings: Tolerance, accumulation and subcellular distribution. *Chemosphere*, 126:471.
2. Jiang Y, Jiang S, Li Z, Yan X, Qin Z & Huang R. (2019). Field scale remediation of Cd and Pb contaminated paddy soil using three mulberry (*Morus alba* L.) cultivars. *Ecol Engin* 129: 38-44.
  3. Wao AA, Khare S & Ganguli S (2014). Extraction and analysis of heavy metals from soil and plants in the industrial area Govindpura, Bhopal. *J Environ Human* 1(2): 158-164.
  4. Cheng SF, Huang CY, Lin YC, Lin SC, & Chen KL (2015). Phytoremediation of lead using corn in contaminated agricultural land—An in situ study and benefit assessment. *Ecotoxicol and Environ Safety* 111: 72-77.
  5. Mataka L, Henry E, Masamba W, & Sajidu S (2006). Lead remediation of contaminated water using *Moringa Stenopetala* and *Moringa oleifera* seed powder. *Int J Environ Sci Technol* 3(2): 131-139.
  6. Diels L, Spaans P, Van Roy S, Hooyberghs L, Ryngaert A, Wouters H & Finlay J (2003). Heavy metals removal by sand filters inoculated with metal sorbing and bacteria. *Hydrometallurgy* 71(1-2): 235-241.
  7. Tembo BD, Sichilongo K & Cernak J. (2006). Distribution of copper, lead, cadmium and zinc concentrations in soils around Kabwe town in Zambia. *Chemosphere* 63(3): 497-501.
  8. Ullah A, Heng S, Munis MFH, Fahad S, & Yang X. (2015). Phytoremediation of heavy metals assisted by plant growth promoting (PGP) bacteria: a review. *Environ Exp Bot* 117: 28-40.
  9. Nagajyoti P, Dinakar N, Prasad T, Suresh C & Damodharam T (2008). Heavy metal toxicity: Industrial effluent effect on groundnut (*Arachis hypogaea* L.) seedlings. *J Appl Sci Res* 4(1): 110-121.
  10. Qishlaqi A & Moore F (2007). Statistical analysis of accumulation and sources of heavy metals occurrence in agricultural soils of Khoshk River Banks, Shiraz, Iran. *Am Eurasian J Agric Environ Sci* 2(5): 565-573.
  11. Herawati N, Suzuki S, Hayashi K, Rivai I & Koyama H. (2000). Cadmium, copper, and zinc levels in rice and soil of Japan, Indonesia, and China by soil type. *Bulletin Environ Contam Toxicol* 64(1): 33-39.
  12. Pakistan MFG (2017). Pakistan Economic Survey, 2016-2017.
  13. Irshad MS. (2015). One belt and one road: dose China-Pakistan economic corridor benefit for Pakistan's economy? *J Econ Sustain Develop* 6(24): 45-53.
  14. Major J (2010). Guidelines on practical aspects of biochar application to field soil in various soil management systems. *Int Biochar Initi* 8: 45-62.
  15. Park JH, Lamb D, Paneerselvam P, Choppala G, Bolan N & Chung JW. (2011). Role of organic amendments on enhanced bioremediation of heavy metal (loid) contaminated soils. *J Hazard Mater* 185(2-3): 549-574.
  16. Sherene T. (2010). Mobility and transport of heavy metals in polluted soil environment. Paper presented at the Biological Forum—An International Journal.
  17. Abril GA, Wannaz ED, Mateos AC, Invernizzi R, Plá RR & Pignata ML (2014). Characterization of atmospheric emission sources of heavy metals and trace elements through a local-scale monitoring network using *T. capillaris*. *Ecol Ind* 40: 153-161.
  18. Ghiyasi S, Karbassi A, Moattar F, Modabberi S & Sadough MB. (2010). Origin and concentrations of heavy metals in agricultural land around aluminium industrial complex. *J Food Agri Environ* 8(3&4): 1237.
  19. Kashem MA, Singh BR, & Kawai S. (2007). Mobility and distribution of cadmium, nickel and zinc in contaminated soil profiles from Bangladesh. *Nut Cycling in Agroecosystems* 77(2): 187-198.

20. Desideri D, Meli M, Roselli C & Feduzi L (2011). Determination of essential and non-essential elements in herbal tea and camomile by polarised X rays fluorescence spectrometer (EDPXRF). *J Radioanalytical Nucl Chem* 290(2): 391-396.
21. Fulekar M, Singh A, & Bhaduri AM. (2009). Genetic engineering strategies for enhancing phytoremediation of heavy metals. *African J Biotechnol* 8(4): 34-42.
22. Mehmood T, Chaudhry M, Tufail M & Irfan N. (2009). Heavy metal pollution from phosphate rock used for the production of fertilizer in Pakistan. *Microchem J* 91(1): 94-99.
23. Chehregani A, Noori M & Yazdi HL (2009). Phytoremediation of heavy-metal-polluted soils: screening for new accumulator plants in Angouran mine (Iran) and evaluation of removal ability. *Ecotoxicol Environ Safety* 72(5): 1349-1353.
24. Shi Z, Tao S, Pan B, Fan W, He X, Zuo Q & Liu W (2005). Contamination of rivers in Tianjin, China by polycyclic aromatic hydrocarbons. *Environ Pollu* 134(1): 97-111.
25. Modaihsh A, Al-Swailem M & Mahjoub M (2004). Heavy metals content of commercial inorganic fertilizers used in the Kingdom of Saudi Arabia. *J Agricul Marine Sci* 9(1): 21-25. Pallavi S & Rama SD. (2005). Lead toxicity in plants. *Braz J Plant Physiol* 17(1): 35-52.
26. Butt MS, Sharif K, Bajwa BE & Aziz A (2005). Hazardous effects of sewage water on the environment: Focus on heavy metals and chemical composition of soil and vegetables. *Manag Environ Quality: An Int J* 16(4): 338-346.
27. Balarak D, Tilaki DR, Yousefi Z, Zazouli M, Yazdani J & Esfandyari Y (2014). Phytodegradation Potential of Phenol from Aqueous Solution by *Azolla filiculoides*. *J Bioremed & Biodegred* 5(7): 1.
28. Singh S. (2012). Phytoremediation: a sustainable alternative for environmental challenges. *Int J Gr Herb Chem* 1: 133-139.
29. Ismail M, Muhammad D, Khan FU, Munsif F, Ahmad T, Ali S & Ahmad M (2012). Effect of brick kilns emissions on heavy metal (Cd and Cr) content of contiguous soil and plants. *Sarhad J Agri* 28(3): 403-409.
30. Vickers NJ (2017). Animal Communication: When I'm Calling You, Will You Answer Too? *Current Biol* 27(14): R713-R715.
31. Mussarat M, Bhatti AU, & Khan FU. (2007). Concentration of metals in sewage and canal water used for irrigation in Peshawar. *Sarhad J Agri* 23(2): 335.
32. Najam S, Nawaz R, Ahmad S, Ehsan N, Khan M & Nawaz M. (2015). Heavy metals contamination of soils and vegetables irrigated with municipal wastewater: A case study of Faisalabad, Pakistan. *J Environ Agri Sci* 4: 6-10.
33. Mushtaq N, & Khan KS. (2010). Heavy metals contamination of soils in response to wastewater irrigation in Rawalpindi region. *Pak J Agri Sci* 47(3): 215-224.
34. Ab Halim N, Kusin FM & Mohamed KN. (2018). Heavy metal exposure from co-processing of hazardous wastes for cement production and associated human risk assessment. *Int J Environ Sci Technol* 15(4): 733-742.
35. Ernst WH. (2000). Evolution of metal hyperaccumulation and phytoremediation hype. *The New Phytol* 146(3): 357-358.
36. Han W, Gao G, Geng J, Li Y & Wang Y (2018). Ecological and health risks assessment and spatial distribution of residual heavy metals in the soil of an e-waste circular economy park in Tianjin, China. *Chemosphere*, 197: 325-335.
37. Caussy D, Gochfeld M, Gurzau E, Neagu C & Ruedel H. (2003). Lessons from case studies of metals: investigating exposure, bioavailability, and risk. *Ecotoxicol Environ Safety* 56(1): 45-51.
38. Oehlenschläger J. (2002). Identifying heavy metals in fish In: Safety and Quality

- issues in fish processing, Bremner, HA: Woodhead Publishing Limited.
39. Lievens C, Yperman J, Vangronsveld J & Carleer, R. (2008). Study of the potential valorisation of heavy metal contaminated biomass via phytoremediation by fast pyrolysis: Part I. Influence of temperature, biomass species and solid heat carrier on the behavior of heavy metals. *Fuel* 87(10-11): 1894-1905.
  40. Shakoor MB, Ali S, Hameed A, Farid M, Hussain S, Yasmeen T & Abbasi GH (2014). Citric acid improves lead (Pb) phytoextraction in *Brassica napus* L. by mitigating Pb-induced morphological and biochemical damages. *Ecotoxicol Environ Safety* 109: 38-47.
  41. Mijal RS & Holzman CB. (2010). Blood cadmium levels in women of childbearing age vary by race/ethnicity. *Environ Res* 110(5): 505-512.
  42. Kavcar P, Sofuoglu A & Sofuoglu SC. (2009). A health risk assessment for exposure to trace metals via drinking water ingestion pathway. *Int J Hygiene Environ Health* 212(2): 216-227.
  43. Khan A, Javid S, Muhmood A, Mjeed T, Niaz A & Majeed A. (2013). Heavy metal status of soil and vegetables grown on peri-urban area of Lahore district. *Soil Environ* 32(1): 49-54.
  44. Beaumont JJ, Sedman RM, Reynolds SD, Sherman CD, Li LH, Howd RA & Alexeeff GV (2008). Cancer mortality in a Chinese population exposed to hexavalent chromium in drinking water. *Epidemiol* 3: 12-23.
  45. Mandal BK, Ogra Y & Suzuki KT. (2003). Speciation of arsenic in human nail and hair from arsenic-affected area by HPLC-inductively coupled argon plasma mass spectrometry. *Toxicol App Pharmacol* 189(2): 73-83.
  46. Mushtakova V, Fomina V & Rogovin V (2005). Toxic effect of heavy metals on human blood neutrophils. *Biol Bullet*, 32(3): 276-278.
  47. Barbier O, Jacquillet G, Tauc M, Cougnon M & Poujeol P (2005). Effect of heavy metals on, and handling by, the kidney. *Nephron Physiol* 99(4): 105-110.
  48. Damek-Poprawa M, & Sawicka-Kapusta K (2003). Damage to the liver, kidney, and testis with reference to burden of heavy metals in yellow-necked mice from areas around steelworks and zinc smelters in Poland. *Toxicol*, 186(1-2): 1-10.
  49. Lin Z, Chen X, Xi Z, Lin S, Sun X, Jiang X & Tian H. (2018). Individual heavy metal exposure and birth outcomes in Shenqiu county along the Huai River Basin in China. *Toxicol Res* 7(3): 444-453.
  50. Silver MK, Arain AL, Shao J, Chen M, Xia Y, Lozoff B & Meeker JD (2018). Distribution and predictors of 20 toxic and essential metals in the umbilical cord blood of Chinese newborns. *Chemosphere* 210: 1167-1175.
  51. Liu Y, Xing J, Wang S, Fu X & Zheng H (2018). Source-specific speciation profiles of PM_{2.5} for heavy metals and their anthropogenic emissions in China. *Environ Poll* 239: 544-553.
  52. Yu MH, Tsunoda H & Tsunoda M (2011). *Environmental toxicology: biological and health effects of pollutants*: crc press.
  53. Garza A, Vega R & Soto E (2006). Cellular mechanisms of lead neurotoxicity. *Medi Sci Moni* 12(3): RA57-RA65.
  54. Bellinger DC (2005). Teratogen update: lead and pregnancy. *Birth Defects Res Part A: Clin and Mol Teratol* 73(6): 409-420.
  55. Pisano A, Santolla MF, De Francesco EM, De Marco P, Rigiracciolo DC, Perri MG & Dolce V (2017). GPER, IGF-IR, and EGFR transduction signaling are involved in stimulatory effects of zinc in breast cancer cells and cancer-associated fibroblasts. *Mol Carcinogenesis*, 56(2): 580-593.
  56. Wei Z, Song X & Shaikh ZA (2015). Cadmium promotes the proliferation of triple-negative breast cancer cells through EGFR-mediated cell cycle regulation. *Toxicol Appl Pharmacol* 289(1): 98-108.

57. Ehsan N, Nawaz R, Ahmad S, Arshad M, Umar M & Mahmood R (2016). Use of ornamental plant “Vinca”(Vinca rosea L.) for remediation of lead contaminated soil. *J Biodiv Environ Sci* 8(3): 46-54.
58. Farooq M, Anwar F & Rashid U (2008). Appraisal of heavy metal contents in different vegetables grown in the vicinity of an industrial area. *Pak J Bot* 40(5): 2099-2106.
59. Li XK, Ji WJ, Zhao J, Wang SJ & Au CT (2005). Ammonia decomposition over Ru and Ni catalysts supported on fumed SiO₂, MCM-41, and SBA-15. *J Catalysis* 236(2): 181-189.
60. McGrath S, Zhao F & Lombi E (2001). Plant and rhizosphere processes involved in phytoremediation of metal-contaminated soils. *Plant Soil* 232(1-2): 207-214.
61. Stals M, Thijssen E, Vangronsveld J, Carleer R, Schreurs S & Yperman J (2010). Flash pyrolysis of heavy metal contaminated biomass from phytoremediation: influence of temperature, entrained flow and wood/leaves blended pyrolysis on the behaviour of heavy metals. *J Analyt App Pyrol* 87(1): 1-7.
62. Witters N, Mendelsohn R, Van Passel S, Van Slycken S, Weyens N, Schreurs E, Vangronsveld J (2012). Phytoremediation, a sustainable remediation technology? II: Economic assessment of CO₂ abatement through the use of phytoremediation crops for renewable energy production. *Biomass Bioenergy* 39: 470-477.
63. Pandey VC (2012). Phytoremediation of heavy metals from fly ash pond by Azolla caroliniana. *Ecotoxicol Environ Safety* 82: 8-12.
64. Sas-Nowosielska A, Kucharski R, Małkowski E, Pogrzeba M, Kuperberg J & Kryński K (2004). Phytoextraction crop disposal—an unsolved problem. *Environ Poll* 128(3): 373-379.
65. Sarma H (2011). Metal hyperaccumulation in plants: a review focusing on phytoremediation technology. *J Environ Sci Technol* 4(2): 118-138.
66. Gupta D, Singh LK, Gupta AD & Babu V (2012). Phytoremediation: An Efficient Approach for Bioremediation of Organic and Metallic Ions Pollutants. *Bioremediation and Sustainability: Research and Applications* (eds R. Mohee and A. Mudhoo). Hoboken, NJ: John Wiley & Sons, Inc, 213-240.
67. Zodrow JJ (1999). Recent applications of phytoremediation technologies. *Remed J* 9(2): 29-36.
68. Erdogan H. (2009). Evaluation of Air Quality in Buildings Located Above TCE and Chloroform Contaminated Plume—A Field Study.
69. Mensa-Wilmot Y, Phillips R, Lee J & Eitenmiller R (2003). Formulation and evaluation of cereal/legume-based weaning food supplements. *Plant Foods Human Nut* 58(3): 1-14.
70. Saberi N, Aghababaei M, Ostovar M & Mehrnahad H (2018). Simultaneous removal of polycyclic aromatic hydrocarbon and heavy metals from an artificial clayey soil by enhanced electrokinetic method. *J Environ Manag* 217: 897-905.
71. Mulligan C, Yong R & Gibbs B (2001). Remediation technologies for metal-contaminated soils and groundwater: an evaluation. *Engin Geol* 60(1-4): 193-207.
72. Lee JY, Lee M & Yu M (2016). Draft Guideline Matching the Treatment Technology to the Soil Contaminated Site Based on the Site Properties in Korea. *J Soil Groundwater Environ* 21(6): 1-13.
73. Yang X, Ye H, Long X, He B, He Z, Stoffella P & Calvert D (2005). Uptake and accumulation of cadmium and zinc by Sedum alfredii Hance at different Cd/Zn supply levels. *J Plant Nut* 27(11): 1963-1977.
74. Gill A, Saggoo M, Ashwell G, Bishnoi N, Dua A, Gupta V & Sawhney S (2008). Chromium accumulation, translocation and chemical speciation in vegetable crops. *Int J Bot* 6(2): 29-35.

75. Zorrig W, Rabhi M, Ferchichi S, Smaoui A & Abdelly C (2012). Phytodesalination: a solution for salt-affected soils in arid and semi-arid regions. *J Arid Land Stud* 22(1): 299-302.
76. Sakai Y, Ma Y, Xu C, Wu H, Zhu W & Yang J (2012). Phytodesalination of a salt-affected soil with four halophytes in China. *J Arid Land Stud*, 22(2): 17-20.
77. Padmavathiamma PK & Li LY (2007). Phytoremediation technology: hyper-accumulation metals in plants. *Water, Air, Soil Poll* 184(1-4): 105-126.
78. Visoottiviseth P, Francesconi K & Sridokchan W (2002). The potential of Thai indigenous plant species for the phytoremediation of arsenic contaminated land. *Environ Poll* 118(3): 453-461.
79. Mendez MO & Maier RM (2008). Phytoremediation of mine tailings in temperate and arid environments. *Rev Environ Sci Biotechnol* 7(1): 47-59.
80. Chehregani A & Malayeri BE (2007). Removal of heavy metals by native accumulator plants. *Int J Agric Biol* 9(3): 462-465.
81. Hooda V. (2007). Phytoremediation of toxic metals from soil and waste water. *J Environ Biol* 28(2): 367.
82. Ghosh M & Singh S (2005). A review on phytoremediation of heavy metals and utilization of it's by products. *Asian J Energy Environ* 6(4): 18.
83. Guo T, Zhang G, Zhou M, Wu F & Chen J. (2004). Effects of aluminum and cadmium toxicity on growth and antioxidant enzyme activities of two barley genotypes with different Al resistance. *Plant Soil* 258(1): 241-248.
84. Anoliefo G, Ikhajiagbe B, Okonofhua B & Diafe F (2006). Eco-taxonomic distribution of plant species around motor mechanic workshops in Asaba and Benin City, Nigeria: Identification of oil tolerant plant species. *African J Biotechnol* 5(19): 23-32.
85. McCutcheon S & Schnoor J (2003). Overview of phytotransformation and control of wastes. *Phytoremediation: transformation and control of contaminants*. Wiley, New York 1-58.
86. Hammer D, Kayser A & Keller C. (2003). Phytoextraction of Cd and Zn with *Salix viminalis* in field trials. *Soil Use Manag* 19(3): 187-192.
87. Brown S, Chaney R, Angle J & Baker AM (1995). Zinc and cadmium uptake by hyperaccumulator *Thlaspi caerulescens* and metal-tolerant *Silene vulgaris* grown on sludge-amended soils. *Environ Sci Technol* 29: 1581-1585.
88. Upadhyay AR, Mishra VK, Pandey SK & Tripathi B (2007). Biofiltration of secondary treated municipal wastewater in a tropical city. *Ecol Engin* 30(1): 9-15.
89. Nan Z & Cheng G (2001). Accumulation of Cd and Pb in spring wheat (*Triticum aestivum* L.) grown in calcareous soil irrigated with wastewater. *Bulletin Environ Cont Toxicol* 66(6): 748-754.
90. Lombi E, Zhao F, Dunham S & McGrath S (2001). Phytoremediation of heavy metal contaminated soils. *J Environ Quality* 30(6): 1919-1926.
91. Mani S, Tabil LG & Sokhansanj S (2006). Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. *Biomass Bioenergy* 30(7): 648-654.