Chapter 13
Biochar-Assisted Phytoremediation for Heavy Metals-Contaminated Soils

Shazma Muzammal, Asma Akram, Muhammad Bilal Shakoor, Sajid Rashid Ahmad, Mujahid Farid, and Muhamamd Hassan Shakoor

Abstract The use of biochar in phytoremediation of heavy metals-contaminated soils is considered a very beneficial approach. The biochar application in phytoremediation method results in the removal, degradation, or stabilization of heavy metals from soil media. Various other chemical, biological and physical techniques are used for the treatment of heavy metals-contaminated soils but biochar application to soils is proved to be a much better option than different conventional methods. Biochar when added to soil can enhance nutrient retention ability, soil structure, water holding capacity and microbial activity thus producing a favorable environment for the growth of plants. Efficient plants are selected for phytoremediation method which is based on their potential to sustain or uptake heavy metals without significant damage to their growth. They show great potential to uptake and sustain high levels of heavy metals in their roots or aerial parts. The biochar application in soil along with phytoremediation can reduce the bioavailability of heavy metals to plants thus restricting their significant uptake. Moreover, it also minimizes the danger of groundwater pollution and dispersion of heavy metals in environment. Overall, biochar-assisted phytoremediation has proved its significance as a capable and ecofriendly method to resolve widespread issue of heavy metals contamination in soils thus presenting a sustainable substitute to conventional treatment methods.

Keywords Accumulation · Biochar · Heavy metals · Phytoremediation · Soils

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S. Muzammal · A. Akram · M. B. Shakoor (✉) · S. R. Ahmad
College of Earth and Environmental Sciences, University of the Punjab, Lahore 54000, Pakistan
e-mail: bilalshakoor88@gmail.com

M. Farid
Department of Environmental Sciences, University of Gujarat, Gujarat, Pakistan

M. H. Shakoor
Department of Chemistry, Riphah International University, Faisalabad, Pakistan

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13.1 Introduction

The importance of soil for the survival of living organisms is very well understood. The presence of certain soil microbes and crucial nutrients in the soil are very essential for its health and fertility. However, deterioration of soil due to heavy metals is one of the main issues across the world. Multiple sites globally, are facing extreme soil destruction and infertility due to the addition of heavy metals as a result of certain anthropogenic activities. The addition of lethal natured heavy metals into soil particularly through waste management activities, industrial and agricultural processes etc. is not only making the soil inhabitable for certain soil microorganisms but also posing a serious threat to food security on a global level. Many scientists have been focusing and researching on the possible sustainable methods that can help the contaminated soil to regain its natural stability. Moreover, a lot of methodologies proposed by different researchers proved that rehabilitation of soil is not an easy task due to certain technical and financial implications. Several physicochemical and biological methods like ion exchange, precipitation, vitrification, land farming, encapsulation, chemical fixation, solidification, composting, bioventing etc. are not considered good to provide the favorable results with lesser or no negative environmental impact. On the contrary, biochar assisted phytoremediation is the one eco-friendly and cost-effective technique that is able to give better results when applied on heavy metals contaminated soil. The use of hyperaccumulators with the amendment of organic biochar has proved to be one of the best methods developed to treat the unhealthy soil. This method has certain amount of benefits over other conventional techniques e.g., it has the potential to immobilize heavy metals in soil, makes the soil stronger for maximum crop yield, increase carbon sequestration potential of soil etc. A variety of biochars has been used along with effective plant species to extract heavy metals out of the contaminated soil. Some of them are; rice husk biochar assisted phytoremediation, tea waste derived biochar assisted phytoremediation, bamboo biochar assisted phytoremediation, banana peel biochar assisted phytoremediation, coconut and hardwood biochar assisted phytoremediation, corn cob and cotton straw assisted phytoremediation etc. Hence, on the basis of remarkable results given by the above mentioned biochars for the removal of heavy metals like Cd, Pb, Zn, As, Cr, etc. this methodology is mostly preferred over others by scientific community.

13.2 Soil as a Background for Living Things

In particular, the soil, which is the top layer of the crust, stands in for the "living epidermis" of the globe. A specific combination of minerals, organic matter, and a channel of pore spaces filled with water and air create the complex habitat known as soils. Many diverse types of soil organisms living here conduct essential soil processes and functions (Kabata-Pendias 2000; Sintim et al. 2022). In addition to being a source and reservoir of pathogens, beneficial microorganisms, and the total microbial diversity in a broad variety of organisms and ecosystems, soils are a crucial component of one's health.

Because of the ecosystem services that the soil provides to sustain life on the planet, its significance should not be understated (Islam et al. 2022). Human food is primarily produced through farming on grassland and arable lands. Additionally, fruitful and sustainable cultivation on agricultural soils will be the foundation of food production for human society in the future (Gerke 2022). As all plant species absorb the inorganic nutrients and water required for their development, the soil serves as the substrate for their survival (Blum 2013; Dong et al. 2021). It creates a natural water filter and regulates the exclusion of extra water. Soluble organic carbon (SOC) is used to hold large amounts of organic carbon (Amoah-Antwi et al. 2020). With about 80% of the world's terrestrial carbon (C) stored underground, soil is the second-largest C sink after the seas. According to estimates, soil organic matter (SOM) contains 58% of the earth's organic carbon (Joos and Tender 2020).

Consequently, soil helps preserve biodiversity by supporting interactions between numerous soil microhabitats, which are home to a variety of species including upper mammals and microorganisms (Sintim et al. 2022; Dror et al. 2021).

The management of soil organic matter for high soil fertility and high carbon storage in soils, which may mitigate for rising CO_2 concentrations in the atmosphere. The supply and cycling of plant nutrients at a high level, which is highly influenced by soil organic matter. Additionally, both now and in the future, the agricultural soils will have a significant impact on the availability of food for an increasing human population (Gerke 2022).

13.3 Heavy Metals (HMs) Pollution in Soil

Heavy metal contamination of soil has become an environmental issue on a global level in recent years. Environmental pollution requires immediate global outlook because it threatens soil and water resources. Heavy metal contamination of soil is mainly driven by accelerated population growth and increased anthropogenic activities, such as the haphazard disposal of municipal refuse and industrial effluents (Shah and Daverey 2020; Irfan et al. 2021). Metals and metalloids with an atomic mass greater than 20 and a chemical density greater than 5 g/cm^3 are classified as heavy metals (Kabata-Pendias 2000; Alloway 2013). Numerous heavy metals have a much greater density than in liquid, ranging from over 4 g/cm^3 to 5 g/cm^3, and are typically toxic to plants, humans, and other animals without consideration to their fixations (Siddeeg 2020).

While anthropogenic activities like excessive sewage disposal, drainage systems, slime applications, diesel exhaust, mineral extraction and refining processes, urban growth, agricultural activities, and industrial growth contributed to the accumulation of heavy-metal contamination in soil, the geography of the area is specifically in need of minor component concentrations in soil condition (Wadhawan et al. 2020). Cadmium (Cd), mercury (Hg), copper (Cu), arsenic (As), lead (Pb), chromium (Cr), uranium (U), and zinc (Zn) are the most prominent HMs found in the atmosphere (Wuana and Okieimen 2011; Qin et al. 2021). According to Jabeen et al. 2009, lead (Pb) can remain in soil for more than 150–5,000 years and can stay there in high quantities for up to 150 years after being applied to the soil as sludge. Cadmium (Cd) has a biological half-life of roughly 10–30 years (Berglund et al. 2015).

Over 20 million hectares of soil have been contaminated by heavy metals globally (Liu et al. 2018). Many heavy metals are necessary for biological systems, but only in small amounts because they are highly toxic at higher levels and can lead to cancer, hyperkeratosis, skin lesions, and issues with the brain, kidneys, and gut (Ayangbenro and Babalola 2017; Akpomie and Conradie 2020).

13.4 Sources of HMs in Soil

The two main sources of heavy metals entering the earth are anthropogenic and natural sources.

13.4.1 Natural Sources

Heavy metal (loids) in contaminated areas can come organically from the parent soil, or geogenic source. Many heavy metals reside in chemical complexes rather than as single molecules, making them easier for living cells and tissues to directly absorb (Derakhshan Nejad et al. 2018). While typical heavy metals include zinc (Zn), lead (Pb), mercury (Hg), nickel (Ni), copper (Cu), arsenic (As), cadmium (Cd), and chromium, heavy metals can also take on other chemical forms in soil, including silicates, hydroxides, sulphides, oxides, organic, and phosphate compounds (Cr). Even though they are present in very small amounts, they are thought to be a significant contributor to issues with human health and the environment. The pedogenic weathering of parent soil materials also explains the trace metal release (less than 1000 mg/kg) of heavy metals into the soil ecosystem (Kabata-Pendias 2000; Oladoye et al. 2022).

13.4.2 Anthropogenic Sources

Due to the constant production of products and mechanical processes to satisfy the high levels of demand from the enormous human population and the concurrent release of effluents or refuse, the environment has become more polluted. Sources of heavy metals include anthropogenic processes like chemical water discharge, wastewater, industrial and farming operations, as well as smelting and mining operations. Due to chemical effluent wastes, soils near industrial metropolitan regions are typically more polluted and contain higher concentrations of heavy metals like Pb, Cu, Cd, and Zn (Oladoye et al. 2022). Some specific heavy metal issues have been linked to certain industrial activities, such as lead (Pb) in automobiles, arsenic (As) in insecticides, zinc (Zn), copper (Cu), and arsenic (As) in smelting processes, and vanadium (V), nickel (Ni), mercury (Hg), tin (Sn), and selenium (Se) in the combustion of fossil fuels (Vhahangwele and Mugera 2015). Agriculture and industry have a significant impact on heavy metal pollution in agricultural soil and plants, especially in soils near cement and electroplating plants (Alengebawy et al. 2021).

13.5 Effect of HMs Contaminated Soil on Environment

In a nutshell heavy metals disrupt the ecosystem's balance, degrade soil qualities, reduce crop yields, and pose serious hazards to human health by getting into the food chain (Shah and Davarey 2020). These heavy metals are toxic in nature because they can harm both people and animals. When a chemical substance can hinder an organism's ability to develop, survive, or reproduce, it is considered toxic. They affect various systems, organs, and tissues in various organisms through a variety of processes, some of which are still unknown (Ali et al. 2019). The distinct physicochemical characteristics and features of each metal define its specific toxicological mechanisms of action. Heavy metals (As, Cr, Cd, Hg, and Pb) have been classified as a public health issue due to their high toxicity. This pollution has gotten worse due to the quickening pace of urbanization and industrialization and increased dependence on synthetic agrochemicals. The high concentration of heavy metals in the soil has a negative effect on soil quality, structure, function, nutrients, and biological activity (Pan et al. 2016).

According to estimates from the National Research Council (NRC) of 2007, there were approximately 45 billion tonnes of materials discovered in 2010 and that number is expected to rise to 70 billion tonnes by 2030. Surface mining leaves behind abandoned ground barren of vegetation, soil structure, and biodiversity (Venkateswarlu et al. 2016). A substantial amount of debris or excess material, which are typically highly contaminated with possibly toxic elements, are typically produced as a result of the excavation activities. However, because of the pH, inadequate levels of biological matter and nutrients, deteriorated pedological structure, low water accessibility, and high levels of dangerous heavy metals, these remains and debris materials cannot provide a favorable substrate for vegetation cover (Wang et al. 2017).

13.6 Impact of HMs Contaminated Soil on Food Security

The second and third Sustainable Development Goals (SDGs) approved by the United Nations general assembly for the year 2030 highlight the importance of reducing food insecurity. It has been observed that contamination with heavy metals in farming soils has increased over the past ten years. This has been ascribed to complexity and a rise in a number of anthropogenic activities, including mechanization, excessive industrialization, and the usage of chemicals (Ashraf et al. 2019; Suman et al. 2018). Heavy metal contamination of agricultural soils is a serious environmental issue and a danger to agricultural output due to their biological half-lives, non-biodegradable nature, toxicity, persistence, and biological accumulation in the food chain (Lü et al. 2018).

It has been established that the levels of metals in food derived from contaminated soil surpass those permitted by law, potentially posing health risks and carcinogenicity. It can result in severe diseases of the liver, lung, nervous system, and immune system as well as bone fractures and malformations, cardiovascular problems, dysfunctional kidneys, hypertension, and other significant diseases of those systems (El-Kady and Abdel-Wahhab 2018). Additionally, consumption of contaminated water and shellfish has been linked to the presence of some xenobiotic heavy metal-based complex compounds (Anani and Olomukoro 2018). These complexes cause the death of both land and aquatic fauna and vegetation when their level of accumulation exceeds their capacity for absorption.

13.7 Various Techniques for Treatment of HMs Contaminated Soils

Consequently, it is crucial to implement cutting-edge and site-specific remediation technologies that can efficiently and securely clean up heavy metal-polluted soils (Ok et al. 2020). Various soil remediation methods have been used over the past few decades (Khan et al. 2015). These techniques concentrate on lowering soil heavy metal maximum and/or bioavailable concentrations and their potential processes in the food supply chain (Ok et al. 2020).

Different chemical and biological techniques and approaches are generally used to effectively remove HMs from soil (Fig. 13.1). According to a study, there are two categories into which soil remediation methods can be divided: (a) ex situ remediation, which entails excavating contaminated soil and treating pollutants afterwards; and (b) in situ remediation, that entails treating the pollutant-target on-site (Li et al. 2019). Furthermore, specific microorganism species are capable of performing the remediation. In contrast, in situ remediation may provide some technological, financial, and environmental benefits (Gholizadeh and Hu 2021). The most effective method must be chosen based on the characteristics of the soil, but it is also important to consider the HM concentration and the intended use of the contaminated soil (Ali et al. 2019).

For the removal of heavy metals from soils that are contaminated, a number of remediation methods have been used, including leaching, adsorption, absorption, electrokinetic remediation, landfilling, and vitrification (Ren et al. 2023a, b). These traditional techniques for cleaning up the environment have a number of drawbacks, including incomplete removal, high energy requirements, the production of a lot

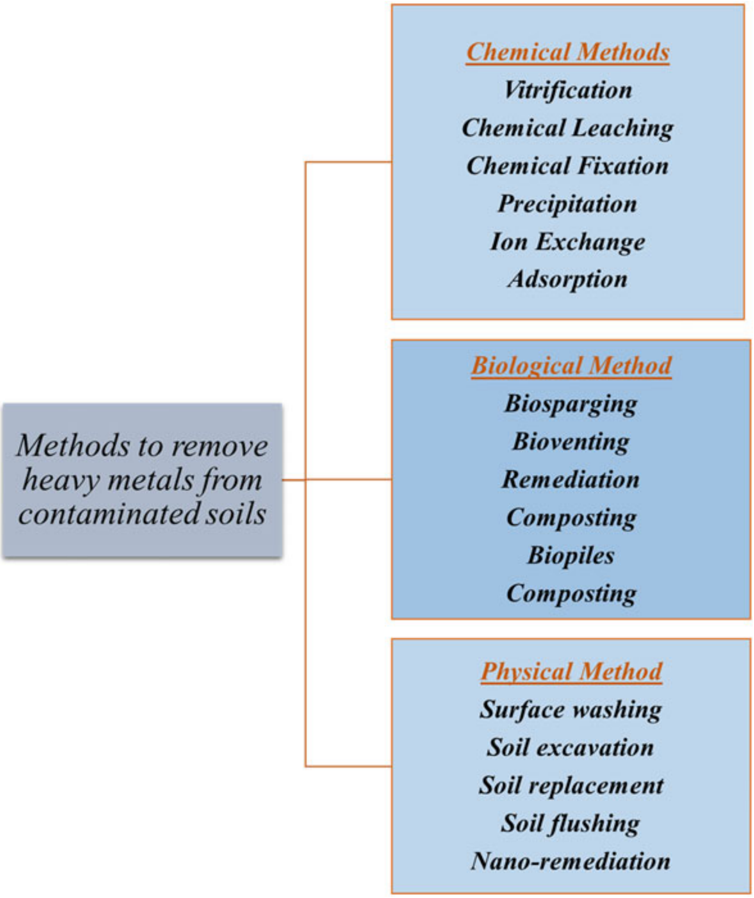

Fig. 13.1 Various techniques to treat heavy metals contaminated soil

of toxic sludge, being restricted to a limited region, and being expensive (Zamora-Ledezma et al. 2021). A traditional physical remediation method can cost between 60 and 90 percent of the total expense of reclamation (Maiti 2012). These techniques are not suitable for use on a broad scale due to their high energy and chemical specifications, as well as their time and cost constraints. These conventional methods, collectively known as "pump and treat" and "dig and dump" techniques, are all confined to limited areas and have drawbacks. By destroying the essential component of soils, these techniques can also disturb the soil's original microflora and result in permanent changes to soil properties. Additionally, the use of chemical technologies can result in secondary pollution issues, which will result in the production of a lot of sludge and raise the expense of sludge management (Awa and Hadibarata 2020).

13.8 Current Trend of HMs Remediation Techniques

Soil remediation is crucial to prevent adverse impacts, lower the probability of toxic metals harming the environment, and assure a healthy environment for future generations (Cristaldi et al. 2017). The heavy metal-contaminated soil is cleaned up using a variety of methods, including soil replacement, thermal desorption, chemical leaching, and electrokinetic remediation (Table 13.1).

Table 13.1 Various techniques to treat heavy metals contaminated soil

Technique	Principles	Pollutant	References
Natural attenuation	Reducing or preventing pollution at contaminated sites by using organic techniques	Zn, Cu	Agnello et al. (2016)
Thermal desorption	Making pollutants more instable with heat or high temperature, and afterwards eliminating them from the soil aggregate	Hg, Cu	Back et al. (2020)
Electrokinetic	Utlising electric potential to remove dirt contamination from straight electric current	Mn, Pb, Cu, Cr	Tang et al. (2017)
Soil flushing	The process of dissolving contaminants in soil with an aqueous solution	Pb, Cu	Lee et al. (2011)
Soil washing	A procedure for scrubbing soil, cleaning it with liquid or a chemical additive, and splitting the clean soil from the contaminants and washwater	Cd	Mu'azu et al. (2018)
Vitrification	A process that involves electrically heating contaminated soil until inert glass forms	Zr, Pb	Dellisanti et al. (2009)
Phytoremediation	An approach that uses living plants to remove hazardous pollutants from water, air and soil	Cu, Ni, Pb, Cr, Zn	Doni et al. (2015)
Incineration	Application of combustion to waste products with contaminants	Cd, Pb	Atanes et al. (2019)
Solidification	When contaminants interact with additives, a process occurs whereby the contaminants become immobile	Cd, Zn	Xia et al. (2019)
Rhizoremediation	A procedure wherein microorganisms in the rhizosphere decompose soil toxins	Cu, Cr	Ontanon et al. (2014)
Oxidation	By means of chemical oxidants to oxidise and degrade organic contaminants in the subsoil of the soil	Cr, Zn, Cd	Guo and Zhou (2020)
Bioaugmentation	Using additional bacterial populations to speed up the bacterial decay of a soil pollutant	Zn, Pb	Sprocati et al. (2012)

13.9 Phytoremediation

The Latin term “remedium,” which means to correct or remove, and the Greek word “Phyto,” which means plants, were combined to form the word phytoremediation. Using specific plant species referred to as hyperaccumulators, phytoremediation is an in-situ remediation method that removes heavy metals from the soil and thereby reduces their mobility (Chandra et al. 2023).

For the restoration of contaminated soil, different physical and chemical methodologies were rejected by scientific communities due to the several limitations like strict labor work, extremely high prices required for treatment and maintenance and certain physico-chemical properties of soil that can make soil harsh for further plant growth (Sheoran et al. 2011). Due to the severe increase in soil pollution and disturbance in food chain over the past few years, scientists were in search of introducing cleaner and eco-friendly method which can help in the extraction of non- biodegradable heavy metals from the polluted soil (Wuana and Okieimen 2011; Gogoi et al. 2021). One of the best alternatives to chemical and physical methods for the heavy metals’ removal from contaminated soil was the development of a technique named bioremediation. It included the immobilization or removal of certain contaminants from soil using natural and organic systems (Lamine and Saunders 2022).

Phytoremediation, an environmental friendly and comparatively cheaper technology was introduced during the last two decades in which plants and associated soil microbial organisms that were genetically modified used to extract contaminants like heavy metals and convert them into less harmful metabolites (Bolan et al. 2014; Mahar et al. 2016). This efficient technology is not only suitable for the extraction of heavy metals but for pollutants like polychlorinated biphenyls, pesticides, radionuclides and organic contaminants as well (Lone et al. 2008; Vithanage et al. 2012). Chaney (1983) was the scientist who brought the idea of phytoremediation and his concept was appreciated and accepted globally because of its certain benefits (Ali et al. 2012).

In-addition, this technique has received special attention due to its feasible nature. During an in-situ phytoremediation, simply plants and sun along with some soil microbes are required to treat heavy metals. Likewise, very less labor force, machinery and cost further makes this method superior and less toxic over other expensive conventional practices (Burges et al. 2017; Yadav et al. 2018). The main objectives of phytoremediation are as follows:

- Utilization of efficient plants (e.g., poplar, willow etc.) in such a way that not only used for metal extraction but also aids in the production of energy (Abhilash et al. 2012).
- Secondly, phytoremediation significantly works to improve the soil quality slowly by making the land sturdier for good crop production (Vangronsveld et al. 2009; Ali et al. 2012).
- Also, this cleaner technology provides the best cost-effective alternative as compared to other physico-chemical methods (Sarma 2011).

13.10 Mechanisms of Phytoremediation

Phytoextraction, Phytostabilization, Phytodegradation, Phytodesalination, Rhizofiltration, Phytodegradation, and Phytoevaporation are some of the processes of phytoremediation (Table 13.2). However, a number of factors, including the plant species, the characteristics of the medium, the bioavailability of the metal, and the incorporation of chelating agents, may impact these mechanisms (Awa and Hadibarata 2020).

13.11 Biochar Assisted Phytoremediation

Since the heavy metals are toxic to plants, the success of phytoremediation relies on the growth of the plant as well as its ability to absorb metal contaminants. A favorable soil additive can be used to promote plant development as well as for soil remediation in order to get around these problems (Rojjanateeranaj et al. 2017). A method that shows potential for cleaning up soil contaminated with heavy metals is biochar-assisted phytoremediation. In the absence of oxygen, organic matter is heated to create biochar, a carbon-rich substance that has been shown to increase soil fertility, structure, and ability to hold water. By lowering the bioavailability of heavy metals and promoting plant development when incorporated into plants, biochar can help with the remediation of soil that has been contaminated by heavy metals (Moore et al. 2018; Pandey et al. 2020).

13.12 Characteristics of Biochar

According to reports, biochar is very efficient at adsorbing a variety of organic compounds, both natural and man-made. Given its exceptionally aromatic nature, a large surface area, micropore volume, and numerous amounts of polar functional groups, biochar has been shown in multiple previous studies to be efficient in the uptake of a variety of organic chemicals, including pesticides, PAHs, and emerging contaminants like steroid hormones (Kookana et al. 2011).

The porous structure, high retention of water, variety of functional groups, excellent cation-exchange capacity, and a broad surface area are some of the distinguishing characteristics of biochar. The sort of feedstock materials and the degree of pyrolysis have the greatest influence on these characteristics (Simiele et al. 2020; Tu et al. 2020).

When using biochar as an amendment to remediate heavy metal-contaminated soils, one should take into account the types of heavy metals present as well as the temperature at which the biochar is produced. This is because the characteristics

Table 13.2 Techniques of phytoremediation

Strategies of phytoremediation	Description	References
Phytovolatilization	It is based on the mechanism in which pollutants are taken up from plants and converted into volatile form so they can be released into the atmosphere	Padmavathiamma and Li (2007)
Phytostabilization	This technique further aids in the prevention of contaminants to make their way in the groundwater and food chain. It is considered as one of the good methods that help in the stabilization of toxic pollutants having great potential to cause damage	Wuana and Okieimen (2011)
Phytoextraction	In this method, removal of certain pollutants takes place from polluted water, soil or sediments. Efficacy of removal depends on multiple factors of plants to be used. For example; they should have an ability to translocate heavy metals, best rate of growth, high tolerance rate against heavy metal accumulation etc. Moreover, utilization of hyperaccumulator plants further helps in the production of very less biomass which is easy to handle	Chaney et al. (1997)
Phytodegradation	In this technique, particularly organic pollutants are degraded by using enzymes instead of microorganisms that are usually present in rhizosphere. This method is however, not suitable for non-biodegradable pollutants	
Phytodesalination	For the better removal of salts from the soils that are heavily affected by salt accumulation, phytodesalination is the most preferred technique. The use of halophytic plants instead of glycophytic plants is noticed to give better results in order to deal with toxic heavy metals present in polluted soil. By the use of this technique, a great decrease in salinity was observed and that ultimately helped in the better growth of plants	Zorrig et al. (2012)
Phytofiltration	Different forms of phytofiltration such as caulofiltrartion (in which shoots of plants are used), rhizofiltration and blastofiltration are involved for the removal of contaminants like heavy metals from polluted water bodies	

of the biochar are dependent on the pyrolysis conditions, such as the highest treatment temperature, moisture content of the feedstock, residence time, and the type of feedstock used (Zhang et al. 2013).

In order to create biochar, a variety of organic wastes and materials have been used, such as raw pine chips, paper-mill waste (Table 13.3), plant tissue, peanut hulls and pecan shells, pine chips and poultry litters, forage plant biomass, citrus wood, bunches of empty fruits, cotton seed hulls, rubber wood sawdust, sewage biosolids, rice husks (Zhang et al. 2013).

Table 13.3 Influence of biochar application on heavy metals bioavailability in soil

Feedstock	Temperature	Contaminant	Effect	References
Eucalyptus	560 °C	Zn, Cu	Reduced As, Cu, Ni levels in maize seedlings	Namgay et al. (2010)
Cotton stalks	400 °C	Cd	Adsorption or co-precipitation can reduce the solubility of Cd and Zn in soil	Zhou et al. (2008)
Orchard prune residue	500 °C	Pb, Ni, Cr, Cd	Cd shows the greatest decrease in bioavailability, with Pb and Zn also significantly reduced; however, pH and Cation exchange capacity(CEC), and water-holding capacity all increased	Fellet et al. (2011)
Green waste & chicken manure	500 °C	Pb, Cu	Cd and Pb deposits are significantly reduced by using Indian mustard plant	Park et al. (2011)
Hardwood	450 °C	As	Considerable As reduction in Miscanthus leaves	Hartley et al. (2009)
Rice Straw	–	Cd, Cu	Significant decrease in Cu, Cd and lead concentrations in polluted soils; detection of biochar functional groups with high Cu adsorption affinity	Jiang et al. (2012)
Oak Wood	450 °C	Pb, Cu	Bioaccessibility is decreased by 12.5%, and bioavailability is decreased by 75.8%	Ahmad et al. (2012)
Sewage sludge	450 °C	Cu, Ni, Zn	Significant decrease in the plant availability of the metals under investigation	Méndez et al. (2012)

13.13 Applications of Biochar Assisted Phytoremediation

According to Ippolito et al. (2012), biochar can enhance the quality of contaminated soil, stabilise heavy metals there, and significantly lower crop exposure to heavy metals. Thus, the use of biochar could possibly offer an innovative approach for the clearing-out of heavy metal-contaminated soils.

1. Reduce heavy metal bioavailability: Biochar has been demonstrated to lessen the solubility of heavy metals by adsorbing the metals to its surface, leaving them less absorbable by plants. As a result, there is less chance of toxicity from heavy metals in vegetation, animals, and people (Ghosh and Maiti 2021).
2. Enhance plant growth: By offering a source of nutrients along with improving soil structure, biochar increases soil fertility and encourages plant development. This is crucial for phytoremediation because strong plants can absorb and metabolise heavy metals more effectively, which allows them to eliminate more of them from the soil (Gholami et al. 2020).
3. Improve soil quality: By raising soil pH, lowering compaction, and enhancing water-holding ability, biochar can enhance soil quality. This encourages plant development and can lessen the likelihood of soil erosion (Gong et al. 2019a, b).
4. Increase carbon sequestration: A carbon-rich substance called biochar can be employed in order to sequester carbon in the earth, thereby reducing climate change. We can remediate heavy metal-contaminated soil using biochar-assisted phytoremediation, and we can also capture carbon in the process (Abbas et al. 2020).

13.14 Rice Husk and Biochar Assisted Phytoremediation

A heavy metal like lead due to its accumulation in plants, particularly when plant roots uptake it, can cause chaos on a large scale. The effect of lead on the health of plants whether directly or indirectly results in the chlorosis of leaf, lesser or no growth, imbalance in the nutrient uptake, improper functionality of enzymes etc. (Hou et al. 2018; Hovmand et al. 2009). Moreover, the toxic level of Pb even triggers the formation of reactive oxygen species (ROS). These reactive species in return reacts with cell organelles, nucleic acids, chloroplast etc. and become a source of damage to plants depending upon their time of exposure (Kumar and Prasad 2018; Ashraf et al. 2015). Despite of various conventional techniques like electrokinetic remediation, ion exchange, vitrification, reverse osmosis etc. metal stabilization is considered as the most useful and environmental friendly technique. This economically stable technique not only helps in dealing with toxic heavy metals but also gives extra stability to soil which ultimately aids in giving better yield (Zama et al. 2018; Ye et al. 2019). Biochar, on the other hand, is gaining much attention due to its unique carbon-rich properties. Particularly, the ability of carbon sequestration makes biochar a rich source for certain benefits like soil stability, less or no greenhouse gas emissions, better nutrient holding capacity etc. (Jefferey et al. 2017; Mohan et al. 2018). Moreover, according to an experiment, leaching loss by lead was reduced to a significant level by using biochar made up of pig manure in organic soils with low carbon rate (Mehmood et al. 2018; Qin et al. 2018). Similarly, another research claimed that a rice plant was used in which mobility of lead was reduced by using wheat straw biochar (Bian et al. 2014). Utilization of biochar along with rice husk ash (RHA), showed great results regarding the soil health and its interaction with metals (Zama et al. 2018). RHA is obtained when rice husk is burned and it is considered as a very valuable by-product from agricultural point of view. It holds the special attention due to its major constituents i.e. upto 50% cellulose, 20% of hydrated silica and lignin that consists of about 25–30% (Kiran and Prasad 2019). Certain properties of rich husk ash like large surface area, light in weight, extremely porous in nature make it an excellent adsorbent to deal with the mobility of deadly metals in the polluted soils (Bhattacharyya and Gupta 2008). In addition, presence of functional groups like phosphate, amino, carboxyl, sulphydryl, phenol and amide assists biosorbents to form complexes with heavy metals and kick them out of the contaminated soils (Singh et al. 2019).

However, during a research, consumption of plant with a metal stabilization technique was tested and for that purpose, a plant species named *Ricinus communis L.,* was used. This plant was selected particularly due to its consumption as a biofuel substrate, exceptional adaptability, good productivity of biomass and above all resistive nature towards different stresses whether biotic or abiotic (Bauddh et al. 2015; Kumar and Prasad 2018). The main purpose of this study was to check the ability of biochar and rice husk that was added as an amendment in *R.communis* to manage the toxicity and mobility of lead in soil (Kiran and Prasad 2019). The experiment was carried out for about 60 days. The results showed that by the addition of rice husk biochar in R.communis, a significant decrease in the lead concentration was observed. Lead was removed by around 80% through shoots, roots and leaves of selected plant (Kiran and Prasad 2019).

13.15 Tea Waste Derived Biochar Assisted Phytoremediation for Cd Removal

Cadmium, another toxic heavy metal became successful in making its way in the river sediments where there is a high risk of its absorption by aquatic plants. The bioaccumulation may result in the destruction of food chain (Huang et al. 2018). Therefore, an immediate economically feasible and environmentally stable technique was required to cope up with this serious issue.

A group of researchers decided to utilize plants along with the biochar in order to check their combined effect to remove cadmium. Biochar, as mentioned earlier has been a great alternative to certain physicochemical techniques for the past few years.

The carbonaceous material helps in improving the microbial activity in soil and also plays an important role in refining phytoremediation (Nie et al. 2018).

However, tea waste derived biochar at different concentrations was used to facilitate the process of phytoremediation in order to get the cadmium out of the river sediments. River sediments on the other hand, serve as a major sink for heavy metal accumulation (Xue et al. 2018). For the experimental purpose, ramie seedlings were selected. Different concentrations of tea waste were added to the sediments contaminated with cadmium and ramie seedlings were cultivated over that area. Results showed that tea waste derived biochar at specific concentrations i.e.100, 500 and 1000 $mgkg^{-1}$, showed greater results by converting the cadmium into less toxic form. Moreover, this conversion also helped in the access of cadmium in cell wall and other soluble parts of the respective cultivated plant. This in return helped in the translocation and accumulation of cadmium in the ramie seedlings. In- addition, this biochar also aided in the reduction of oxidative stresses in ramie seedlings and enhanced the function of different enzymes like phosphate, urease etc. to lower down the level of cadmium in the contaminated soil. The conclusion showed that tea waste derived biochar was proved to be very beneficial in the cadmium removal even at low concentrations (Gong et al. 2019a, b).

13.16 Biochar and Compost Supported Phytoremediation of *Moringa Oliefera*

Similar to the above mentioned experiments, another biochar assisted phytoremediation was performed by using *Moringa oliefera* in order to check the potential of this plant towards lead toxicity (Ogundiran et al. 2018). Lead noxiousness in plants has produced certain amount of lethal diseases. According to a research, the level of lead upto 900 mg/kg can certainly results in the extreme ecological risk to microbes present in soil (Zeng et al. 2007). Due to its very less negative environmental impact and sustainable nature, phytoremediation is gaining much recognition. The translocation of contaminants like heavy metals from roots to shoots is very useful for the soils that are contaminated with different pollutants (do Nascimento et al. 2006; Doumett et al. 2008). Moreover, specialized plants used for this purpose are termed as hyperaccumulator plants (Wong 2003).

During the experimentation, rice husk biochar and groundnut shell biochar were used along with sunflower-poultry manure compost. All the products were selected based on different physical parameters like particle size, cation exchange capacity, availability of macronutrients etc. Before their utilization in the experiment, the seeds of overnight soaked M. Oliefera were subjected to two weeks incubation period and then transplanted in the soil. Both of the biochars were individually applied in a certain ratio and faced the incubation period of two weeks into the soil. After that, for about two weeks, application of Moringa Oliefera was done in the soil. Certain physical properties of plants like number of leaves, growth of stem, plant height was observed for upto 8 weeks. Moreover, lead concentration after 8 weeks was noticed to be about 2100 mg/kg in the roots and shoots of the respective plant. This resulted concentration showed the ability of M. Oliefera to deal with lead toxicity. Furthermore, addition of compost also improved the metal extraction capability of roots and shoots of M. Oliefera. Hence for soil that is particularly contaminated with lead, the combination of biochar, compost and M. Oliefera was proved to be best to get rid of lead contamination (Ogundiran et al. 2018).

13.17 Bamboo Biochar Assisted Phytoremediation

Willow (Salix spp.), a woody species that grows quickly and is resistant to metals, is an appropriate choice for phytoremediation. Salix also generates a lot of biomass, which can be used for energy generation and easy disposal. Salix also has a number genetic variations, rapid growth, a deep and extensive root system, the ability to sprout again after harvest, high levels of activity of antioxidant enzymes in the leaves, effective transpiration, and a high capacity for nutrient uptake (Cao et al. 2017).

Bamboo biochar (BBC) has a large specific area, abundant microporous and mesoporous structure, as well as high HM adsorption capacity (Ouyang et al. 2014), which suggests its tremendous potential as a soil amendment (Ouyang et al. 2014). Bamboo biochar (BBC) is a carbonaceous substance that contains a lot of organic matter and can significantly improve the soil organic matter (SOM).

The application of bamboo biochar could stimulate the roots to produce organic acids. According to reports, root exudate can accelerate the release of leftover metal and subsequently mobilize HMs in the rhizosphere (Lefevre et al. 2013). To increase the amount of dissolved organic matter (DOM) in soil, applied Bamboo biochar (BBC) can discharge DOM into the soil (Li et al., 2018). By forming soluble organometallic complexes with metals, the organic ligands in soil DOM can trigger HMs (Li et al. 2020). Overall, the BBC amendment can enhance the root environment of plants and encourage the action of soil enzymes (Kolton et al. 2011).

According to Batty and Dolan (2013), adding BBC could hasten the uptake of nutrients and water while improving the roots' capacity to assimilate Cd, Zn, and Cu from the rhizosphere. This would increase the absorption as well as accumulation of HMs in the plant. According to Habiba et al. (2015), adding BBC could improve plants' ability to interchange gases, which would subsequently boost the mobility of Cd, Zn, and Cu from the soil to the plant's above-ground tissues. Previous research (Salam et al. 2019) also indicated that the improvement of SOM, N, P and K by amendment, facilitating the development of plants and the accumulation of HMs (Cu, Zn, Cd and Pb).

13.18 Banana Peel Biochar Assisted Phytoremediation for Cd Removal

Heavy metal Cd is regarded as a non-essential element for vegetation. According to reports, Cd is harmful to plants, causing necrosis and a deficiency in the photosynthetic process. Chlorophyll, plant development, and phytobiomass are all negatively impacted by these unbalanced physiological processes.

The banana fruit is an extensively grown crop and is eaten all over in the globe. It is the second most widely cultivated fruit product worldwide. Peels from bananas are regarded as a refuse item of the banana industry. It is the most significant organic source of potassium, a crucial macronutrient for developing plants and healthy soil. Despite this, there is a lack of use for banana skin biochar, which has industrial uses (Shah et al. 2022). Banana peel waste and its biochar have been extensively used and acknowledged as a potent waste for the remediation of heavy metal-contaminated water in numerous studies as an absorbent to remove heavy metals from an aqueous system (Akpomie and Conradie 2020).

Banana skin biochar has also been linked to improvements in soil's biochemical characteristics and a decrease in greenhouse gas emissions (Sial et al. 2019). Banana peel disposal is also made possible by the use of banana peels as biochar in phytoremediation. To the best of our understanding, there haven't been any studies done yet on the use of banana peel biochar in phytoremediation of heavy metals (Shah et al. 2022).

In new research, the remediation of Cd-contaminated soil using B. Pilosa plant utilizes banana peel biochar as soil amendment. It was discovered that the physiological traits of the B. pilosa are differentially influenced by banana peel biochar (Root, shoot, dry biomass and chlorophyll). The banana skin biochar may have a beneficial impact on the enzymes urease, dehydrogenase, shoot length, and root length (Nigam et al. 2019).

Banana peels were utilized in this research to create biochar. Fresh banana leaves were washed in distilled water and dried at 80 °C until they reached a consistent weight to make biochar. The desiccated banana peels were ground up and pyrolyzed in an oxygen-restricted muffle furnace for two hours at 500 °C (Bashir et al. 2018). A 0.5 mm sieve was used to further grind and sieve the pyrolyzed product. The biochar was dried at 80 °C after being washed multiple times with distilled water, and it was then placed in a glass receptacle for later use. The pH, electrical conductivity, surface morphology, and functional groups on the surface of the produced biochar were used to characterize it.

It had been found that in treatments with both concentrations of Cd (5 mg/kg and 20 mg/kg), biochar applied at a greater application rate resulted in the maximum Cd uptake by a shoot. The highest Cd uptake in shoots was seen in treatments using the lowest Cd concentration (5 mg/kg) and the greatest biochar concentration (200 mg/kg), which were followed by treatments using no biochar and biochar at low concentrations (Shah et al. 2022).

The application of more biochar with Cd contamination, however, demonstrated greater Cd uptake and accumulation in the root and shoot. In order to increase phytoremediation of heavy metal-contaminated soil, it is proposed that the combination of banana peel biochar with heavy metal accumulator plants may be a viable option (Wang and Wang 2019).

13.19 Date Palm Magnetized Biochar Assisted Phytoremediation

The introduction and accumulation of different heavy metals in soil is facilitated by mining activities, which eventually results in serious environmental pollution (Table 13.4). Such contaminated soils might be restored through the use of different immobilising substances. As a result, date palm-derived biochars (BCs) (BCs: produced at 300 °C, 500 °C and 700 °C) and magnetized biochars (MBCs) were used in this research to stabilise heavy metals (Cd, Pb, Cu, and Zn) in mining contaminated soil (Rodriguez-Franco and Page-Dumroese 2021).

The waste from date palms was gathered, dried at 60 °C, cut into pieces measuring about 3–5 cm, ground, and separated using a sieve of 0.5 mm. The sieved components were pyrolyzed at temperatures of 300 °C, 500 °C, and 700 °C for 4 h to create non-magnetic BC. In the meantime, the sieved materials were treated with a solution of ferrous chloride and ferric sulphate and the pH was increased to 11 using NaOH to create magnetic biochar (MBCs). Following filtration separation, the materials were repeatedly rinsed in distilled water before being dried in an oven tuned to 60 °C (Alazzaz et al. 2023).

Non-magnetized BCs and MBCs both had distinctive surface characteristics that varied depending on the decomposition temperature. In general, BCs and MBCs produced at lesser temperatures for pyrolysis (BC-300 and MBC-300) had higher moisture contents and volatiles, whereas BCs and MBCs produced at 700 °C had higher ash and residual crabon contents as well as higher EC and pH. The probability for immobilizing soil-borne metals and reducing their concentration in shoots and plant uptake was increased in all of the synthesized BCs and magnetized BCs. The soil treated with magnetized BCs revealed the greatest reductions in soluble Cu (70%) and Zn (64%) concentrations, whereas Cd and Pb were found to be below detection limits (Alazzaz et al. 2023).

13.20 Conclusion

The major human-caused events that lead to the contamination of soil from heavy metals are mining, industrial processes, and agriculture. When fertilizers are used for agricultural purposes and gardening, heavy metals like Zn, Cd, Cu and Pb are

Table 13.4 Different biochar assisted phytoremediation methods to treat heavy metals

Type of biochar	Type of plant used	Treated heavy metal	Result	References
Rabbit manure waste	*Brassica Napus*	Co, Pb, Zn, As, Cr and Cu	Reduction of Cobalt by 32%, Lead 95% and Arsenic 98%	Gasco et al. (2019)
Pinewood	*Salix alba, S.purpurea* and *S.viminali*	As and lead	No significant decrease in arsenic but reduced the lead concentration by 70%	Lebrun et al. (2017)
Bamboo (*Bambusa vulgaris*)	*Brassica napus*	Cr, Ni, Pb, Zn, Cu, Cd	Reduce the concentration of Pb, Zn and Cu by 71%, 53% and 84% respectively	Munir et al. (2020)
Coconut and Hardwood	*Salix dasyclados*	Pb and As	Upto 78% removal of Lead	Lebrun et al. (2020)
Oak, Hornbeam and Beech	*Phaseolous vulgaris*	As and Pb	Removal of lead by 90% in soil pore water	Nandillon et al. (2019)
Corn con	*Jatropha curcas*	Cu, Pb, Zn and Cd	Decrease Cd by 70%, Pb by 53% and Zn by 41%	González-Chávez et al. (2017)
Sewage sludge and pruning trees	*Sarcocornia fruticosa*	Cd, Zn and Pb	Significant reduction of Pb, Zn in roots of plants	Álvarez et al. (2020)

released. It is possible to turn biochar assisted phytoremediation into a workable technology for cleaning up contaminated soils. Of course, biochar has the potential to lessen the bioavailability and effectiveness of both organic and heavy metal contaminants in soil. The effectiveness of remediating contaminated soils can be impacted by the extremely heterogeneous physicochemical properties of biochars made from various biomass materials and under various pyrolysis circumstances (such as temperatures). Hence biochar in combination with phytoremediation con be a potential option for treatment of heavy metals contaminates soils.

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