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Remediation of Heavy Metal Contaminated Sites by Application of Biochar: A Review with Future Prospects

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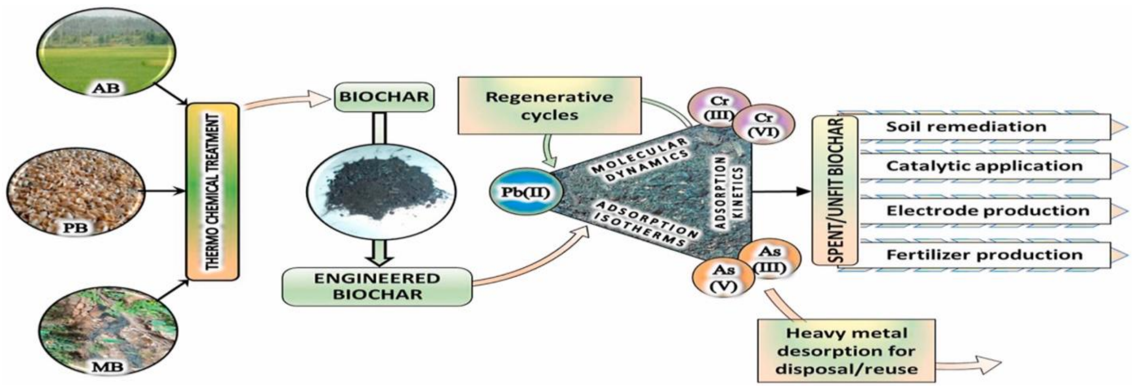
ABSTRACT

Unreasonable mining and smelting of mineral resources, solid waste disposal, sewage irrigation, and the use of pesticides and fertilizers would cause a significant amount of heavy metal pollutants to enter the water and soil environment, endangering human health and ecological security. Heavy metals have the potential to build up in the food chain, and eventually make their way into human bodies via the intake of polluted water, crops, or animals. A prolonged exposure to heavy metals may result in a variety of health difficulties, including neurological diseases, organ damage, developmental troubles, and even some forms of cancer. Pollution from heavy metals may have a negative impact on ecosystems and on species. Heavy metal pollution in water bodies poses a significant threat to aquatic creatures like fish and other aquatic species, which are especially susceptible to the effects of this contamination. It may result in a reduction in the biodiversity of an area, issues with reproduction, and even a loss in population. The development of plants is negatively impacted by soil pollution, which may also have a negative effect on the creatures that are dependent on these plants. In recent years, the majority of researchers have attempted to remove heavy metal contaminants by using biochar, which has a number of benefits including broad raw material sources, cheap cost, and high environmental stability. In order to give some technical support for the application of biochar into heavy metal contaminated soils, the purpose of this study was to examine the definition of biochar as well as its characteristics, the mechanism of heavy metal sorption by biochar, as well as certain issues and possibilities linked to these topics.

Key words: Heavy Metals, Biochar, Wastewater, Environmental pollution, Adsorption

Graphical Abstract



1. INTRODUCTION

Heavy metals are a major contributor to water contamination, which is a major environmental problem. Heavy metals such as lead, mercury, cadmium, chromium, and arsenic are able to make their way into bodies of water via a variety of pathways. These pathways include industrial processes, mining operations, agricultural practices, and inappropriate waste disposal. Heavy metals are able to get into water bodies in a number of different ways, including atmospheric deposition, mining effluents, industrial wastewater discharges, and runoff from polluted land. Common causes of heavy metal contamination include mining, metal smelting, manufacturing, and electroplating industries. In the environment, heavy metals are difficult to degrade and may linger for a very long time. They have the capacity to build up in aquatic creature's tissues, which may biomagnify the food chain. The concentration of heavy metals rises when bigger species devour smaller ones, suggesting a greater danger to higher-level predators, such as humans.

In 2014, the Ministries of Environmental Protection and Land and Resources issued the National Soil Pollution Investigation Gazette, which stated that 16.1% of all soil in China was polluted. Soil pollution in China is mostly the result of decades of fast development, intense agricultural practices, inappropriate waste management, and the use of chemicals such as fertilizers and pesticides. In certain areas, industrial activities such as mining, manufacturing, and garbage incineration have been substantial contributors to soil contamination. The effects of soil contamination are extensive and may have negative effects on ecosystem health as well as human health. Affected agricultural goods may be of worse quality and safety, causing risks to the food supply as a result of contaminated soil. It may also pollute water sources by leaching and runoff, compounding the situation. Inorganic pollution points made up 82.8% of the total standard points, and heavy metals made up the majority of polluters.

According to the data that you presented, the Chinese Ministries of Environmental Protection and Land and Resources published the National Soil pollution Investigation Gazette in 2014, which found that inorganic pollution accounted for 82.8% of all standard points. The primary contributors of inorganic pollution are now known to be heavy metals. Heavy metals such as lead, mercury, cadmium, chromium, and arsenic are often discovered in workplace environments such as mines, factories, and other locations where people are employed. When there is an excessive amount of these metals in the environment, they are dangerous and may be detrimental to both the health of individuals and the globe as a whole. The pollution of the soil by heavy metals is becoming an increasingly serious issue. This not only results in a loss in soil fertility, which in turn reduces agricultural productivity and quality, but it also presents a danger to human health via the chain of food production. The presence of heavy metals in the soil has the potential to disrupt the ecosystems that exist there and to change the soil's chemical, biological, and even physical properties. They have the potential to alter the pH of the soil, so reducing the amount of nutrients that are readily available, and they may inhibit the operation of soil microorganisms, which are a crucial component of the process of nutrient cycling. These changes may bring about a decline in the fertility of the soil, which will have a significant impact on agricultural productivity as a result of its negative repercussions. There is a possibility that the presence of heavy metals in the soil will have an immediate and major effect on the development and growth of plants. Heavy metals have the potential to have a wide range of deleterious effects on plant life, some of which include stunted growth, lower yields, and a drop in the quality of agricultural produce. Heavy metals may be absorbed by crops that are cultivated in polluted soil, rendering such crops either dangerous for human consumption or unsuitable for sale on the market [1]; hence, it is crucial to create a method for repairing heavy metal contamination that is environmentally acceptable. It is essential to create techniques for heavy metal pollution cleanup that are acceptable to the environment. These techniques seek to efficiently decrease or remove heavy metal contaminants from soil while causing the least amount of new environmental impact possible [2].

It has been shown that biochar has the capacity to act as a catalyst for the removal of heavy metal pollutants from the environment. Singh et al., [3]; Liu et al., [4] shown that biochar, which is a material that is abundant in carbon and that is produced as a byproduct of the pyrolysis of biomass, has the ability to facilitate the removal of heavy metal contaminants from the environment. A number of studies have shown that varying pyrolytic temperatures, raw materials, and other factors might influence the ash concentration, carbon content, aromaticity, pH, and other properties of biochar, which further impacted the repair effect of biochars on heavy metal pollution [5]. The remediation of polluted soil brought on by heavy metals requires, as a result, the use of biochar restorers that are shown to be successful.

2. BIOCHAR

During the pyrolysis process, biomass (such as wood chips, crop residues, or agricultural waste) is burned in the absence of oxygen. This results in the synthesis of a material known as biochar, which is rich in the element carbon. In addition to the production of other byproducts such as gases and bio-oil, the thermal decomposition of the biomass results in the formation of biochar.

According to Sohi et al. [6], Li et al. [7], and Xu et al. [8], biochar is a kind of solid material that is insoluble, stable, strongly fragrant, and rich in carbon that is created from discarded biomass under the circumstances of hypoxia and high temperature slow pyrolysis (usually at 700 °C). The bulk of the discarded biomass consists of different types of wood, as well as agricultural waste, plant tissue, and animal waste. Biochar is a unique kind of environmentally beneficial material that has attracted a lot of interest in the disciplines of environmental amendment and agricultural science because it offers substantial potential for improving soil quality, cleaning up pollutants, and making use of residual biomass resources. This is because biochar is a novel form of ecologically useful substance. Because of its unique features and prospective advantages, biochar has received a lot of interest in the realms of environmental amendment and agricultural research. Because of its stable and carbon-rich composition, it can survive in the environment for longer periods of time, making it an efficient long-term carbon sink. This property adds to its ability to mitigate climate change by sequestering carbon from the atmosphere.

3. THE PROPERTIES OF BIOCHAR

Sludge biochar, animal faeces biochar, and plant residue biochar are the three categories that biochar falls under, depending on the source of the biomass components. It is made up of several types of biochar, including animal dung, bamboo, straw, and woody biochar. Biochar produced from sludge is called "sludge biochar," and it is formed from sewage sludge, which is the leftover material that is produced during the treatment of wastewater. The pyrolysis of sewage sludge results in the production of biochar, which has a wide range of potential uses, one of which is the amendment of soil. The pyrolysis of animal waste products, such as manure from cattle or droppings from poultry, is the biochar that comes from animal feces. During the pyrolysis process, the organic matter that is found in animal feces is converted into biochar, which is then suitable for use as an organic soil amendment as well as for other applications. The production of biochar from plant leftovers involves the use of a number of different agricultural wastes and plant biomass. Biochar made from materials such as agricultural wastes (such straw, husks, or stalks), wood waste, and other organic plant-based components. Biochar made from plant waste is often applied to soil in order to improve both the quality and fertility of the soil.

a. ASH AND MINERAL ELEMENTS

With a carbon concentration of more than 60%, aromatic hydrocarbons, single carbons, carbons with graphite structures, and other elements including H, O, N, and S make up the majority of biochar. The chemistry of the raw material and the temperature at which the pyrolysis is carried out have a major influence on the features of the biochar. According to Cao et al. [9], when the temperature increases, the volatile components of biochar, as well as its hydrogen and oxygen content, decrease. On the other hand, the biochar carbon and ash contents constantly climb. The ash contents of biochar produced from animal waste and sludge are clearly going to be larger than those produced from plant residue biochar. This is owing to the fact that the majority of the mineral elements and nutritional elements that are abundant in animal waste and sludge do not decrease with temperature but rather increase as the temperature rises. Due to the higher ash content, animal waste and sludge biochars tend to exhibit a greater cation exchange capacity (CEC) and a higher quantity of exchangeable ions compared to plant residue biochar. The presence of these mineral elements and exchangeable ions can influence the biochar's interactions with soil and its ability to retain and release nutrients. When choosing the right form of biochar for a given application, it is critical to take these differences in composition and qualities into account. This is because various biochar types may have varied impacts on soil properties and nutrient availability depending on their elemental and chemical makeup.

b. AROMATICITY PROPERTIES (H/C AND O/C)

According to Chum et al. [10] and Chen et al. [11], both H/C and O/C have the potential to act as markers of the aromatization of biochar. The temperature at which the biochar was pyrolyzed is directly correlated to its aromatic quality. The pore structure and crystalline structure of biochar both undergo substantial changes as the temperature at which pyrolysis occurs increases. During the dewatering and polymerization processes, the lignin and cellulose in the plant residue biochar break down into smaller molecules, which results in a decline in the ratio of hydrogen to carbon and oxygen to carbon. Animal feces and sludge biochar, however, contain no lignocellulosic chemicals, and their carbon concentration is much lower than that of plant leftovers. Because of this, plant residue biochar clearly has a greater aromaticity than the other two. According to Chen et al. [11], the aromatic structure of biochar has the potential to act as either an electron donor or an electron acceptor, therefore generating pollutant-bonds with pollutants and increasing the adsorption impact of biochar on pollutants.

c. SURFACE STRUCTURE AND FUNCTIONAL GROUPS

The temperature at which the pyrolysis process takes place as well as the components that are added into the biochar also has an effect on its surface form and structure. Due to the degradation of the fat's alkyl and ester groups and the exposure of the aromatic lignin molecules to the surface, the surface area increases as the pyrolysis temperature rises [12]. The surface areas of biochar made from animal feces and sludge are smaller than those made from plant residues. This is because animal feces and sludge biochar have lower carbon contents, higher H/C and O/C ratios, and less aromatization than plant residue biochar. In addition to this, there are discernible changes in the structural functionality of the biochar. In contrast, biochar produced at lower temperatures contains more oxygenic functional groups, and the adsorption of heavy metals on this biochar is primarily attributed to complexation with the functional groups rather than its strong aromaticity and -bond.

d. pH OF BIOCHAR

The vast majority of biochar has an alkaline pH, and the alkalinity of the biochar increases as the temperature of the pyrolysis process rises. According to Xu et al. [8] and Cao et al. [9], the higher pH of biochar may be due to the presence of a significant number of alkaline salts, alkali metals (Na, K, Ca, and Mg), and $CaCO_3$. The raw materials that are used to make biochar may have a significant impact on its pH, with animal dung having a pH that is noticeably higher than that of plant waste. According to Ahmad et al. [13], high pyrolysis temperatures not only support the formation of acidic soil, but they also enhance the development of metal hydroxide precipitation and the adsorption of heavy metals.

4. SORPTION MECHANISMS OF METAL BY BIOCHARS

The removal of hazardous substances including lead, cadmium, mercury, and other heavy metals has been the principal focus of research in recent years. Heavy metals, in contrast to organic pollutants, are more difficult to biodegrade, which makes the process of contamination cleanup more difficult. The novel material known as biochar, on the other hand, has an enormous surface area, a porous structure, and a great deal of surface functional groups, all of which have the potential to effectively repair a certain amount of heavy metal contamination [14].

Biochar has shown promise as a possible method for removing heavy metal pollution due to the large surface area its porous structure, and the abundance of surface functional groups it possesses. As a result of the properties that it has, biochar is an effective adsorbent for heavy metals. It reduces the bioavailability of the contaminants as well as the potential damage they may do to the environment by binding and immobilizing them. Heavy metal adsorption may take place on a lot of biochar's surface area. The metal ions have easier access to these adsorption sites because of the porous structure. Heavy metals may attach to the surface functional groups, such carboxyl and hydroxyl groups, which makes it easier to remove them from the environment. Currently, the adsorption mechanism of biochar on heavy metal pollutants has not been determined, but the following are generally considered to be the most important mechanisms:

a. ION EXCHANGE AND ADSORPTION OF CATIONIC Π FUNCTION

The exchange adsorption that takes place on the surface of biochar is a significant contributor to the reduction of heavy metal activity. According to Lehmann [15] and Reesa et al. [16], the retention of heavy metals is proportional to the number of cation exchanges present. Ion exchange happens when clusters of negative charges on the surface of biochar interact electrostatically with clusters of positive charges in the soil. This interaction creates a net positive charge in the soil. This kind of reaction, which falls under nonspecific adsorption and has lower adsorption energy, is clearly reversible. The aromatization of biochar is necessary for the cationic action. The capacity of function groups to lose electrons rises and the importance of the adsorption effect grows when the conjugate aromatic structure is present in increasing quantities. An essential process through which biochar retains heavy metals is exchange adsorption. Positively charged ions (cations), including those from heavy metals, may interchange with other cations present in the environment thanks to the existence of cation exchange sites on the surface of biochar. The biochar retains the heavy metals as a result of this cation exchange mechanism. Exchange adsorption is a kind of nonspecific adsorption, which means that the positive charges of the cations and the negative charges on the surface of the biochar interact electrostatically. The adsorption of heavy metals onto biochar is reversible because nonspecific adsorption often has lower adsorption energies. This reversibility may affect the long-term stability of heavy metal retention in soils modified with biochar. Its cation exchange capacity and ability to adsorb heavy metals are both significantly influenced by the aromatization of biochar, which is the presence of a conjugated aromatic structure. Functional groups on biochar surfaces have a greater ability to lose electrons when an aromatic structure is present, which enables them to interact cationically. This increases the adsorption action and improves the retention of heavy metals [17].

b. COPRECIPITATION

By adsorption and dissolution-precipitation of mineral constituents, biochar may effectively lower the activities of heavy metals. According to Reesa et al. [16], adding biochar may raise the pH of soil, and when heavy metal ions combine with -OH, PO_4^{3-}, or CO_3^{2-}, they can precipitate as hydroxide, carbonate, or phosphate, effectively solidifying the heavy metal contaminants. Through ion exchange, surface complexation, and electrostatic interactions, biochar may absorb heavy metal ions onto its surface. On biochar, there are many functional groups and a large surface area, which provide heavy metals binding sites. The bioavailability and mobility of heavy metals in the environment are both decreased by the adsorption process.

Biochar may affect the activity of heavy metals via dissolution-precipitation pathways in addition to adsorption. The pH of the soil environment may rise with the addition of biochar. As the pH rises, hydroxide ions (-OH) may develop, which may then interact with heavy metal ions. Heavy metal hydroxides may precipitate as a consequence of this reaction, which will reduce their solubility and effectively immobilize them. Solid precipitates may develop when certain anions, such as hydroxide (-OH), phosphate (PO_4^{3-}), or carbonate (CO_3^{2-}), react with heavy metal ions. These precipitates have lower solubilities, are typically less bioavailable, and are less mobile in the environment. Examples include metal hydroxides, metal phosphates, and metal carbonates. This procedure lessens the danger to the environment by helping heavy metal pollutants settle.

c. COMPLEXATION

For the fixation of heavy metal ions with high affinity, this complexation is significant. Numerous studies have shown that the interactions of heavy metal ions with oxygenic functional groups, such as the hydroxyl (-OH), carboxyl (-COOH), and amino-group (-NH_2) on biochar surface, greatly contribute to the adsorption of heavy metal ions. On its surface, biochar has a number of oxygenic functional groups, including hydroxyl (-OH), carboxyl (-COOH), and amino-group (-NH2) groups. These functional groups may form connections with heavy metal ions because they are often polar and contain lone pairs of electrons.

Heavy metal ion complexation contacts are possible thanks to the oxygenic functional groups on the surface of the biochar. Heavy metal ions may bind to the surface of the biochar via coordination bonds formed by the lone pairs of electrons in the functional groups. Biochar has a higher affinity for heavy metal ions due to the presence of oxygenic functional groups. In order to create coordination complexes with heavy metal ions, the oxygen atoms in hydroxyl, carboxyl, and amino groups as well as the nitrogen atoms in these groups may function as electron donors. This improves the biochar's ability to adsorb and its selectivity for heavy metal ions. The total adsorption capacity of biochar for heavy metal ions is greatly influenced by the interactions between oxygenic functional groups and heavy metal ions. The amount of heavy metal adsorption depends on the presence and accessibility of these functional groups on the surface of the biochar.

d. ELECTROSTATIC ABSORPTION

Larger surface areas and greater surface energies allow biochars more effectively absorb and eliminate heavy metal contaminants from the soil. The remediation strategy of biochar for various heavy metal contaminants varies, as shown in table 1. When the biochar is different, the adsorption process for the same heavy metal ion differs. Numerous variables, including the biochar's starting materials, pyrolysis temperature, soil pH, the physical and chemical characteristics of the heavy metal ions, and the quantity of biochar added, affect the adsorption impact of biochar on heavy metal ions. According to studies, animal faeces biochar has a stronger adsorption impact on heavy metal ions than sludge biochar and plant biochar under the same conditions, although having a larger surface area. This is due to the fact that P-rich biochar produced from animal manure may react with specific heavy metal ions via coprecipitation or precipitation and contribute most significantly to the healing process. Studies also revealed that of the three types of biochar, animal feces biochar had the greatest adsorption effect on Pb^{2+}. For the adsorption and removal of heavy metal pollutants from the soil, biochar with bigger surface areas and higher surface energies offers more active sites. The increased surface area improves the interface between biochar and heavy metal ions, boosting its capacity for adsorption and remediation efficacy. Depending on the exact heavy metal pollutant, biochar's treatment approach may change. Depending on the properties of the biochar and the heavy metal ions, various heavy metals may have differing affinities for biochar and may experience various interactions, such as adsorption, coprecipitation, or precipitation. The effectiveness of biochar in adsorbing heavy metal ions depends on a number of factors. These factors include the initial components of the biochar, the pyrolysis temperature, the pH of the soil, the physical and chemical properties of the heavy metal ions, and the quantity of biochar applied. These elements have a substantial impact on the ability of biochar to bind heavy metal pollutants and how effective it is in doing so. Animal feces biochar, sludge biochar, plant biochar, and other forms of biochar may all have different effects on the adsorption of heavy metal ions. Under the same circumstances, animal feces biochar may, although having a higher surface area, have a better adsorption impact on heavy metal ions than sludge biochar and plant biochar. This might be explained by the presence of biochar made from animal dung that is high in phosphorus (P), which can contribute to coprecipitation or precipitation interactions with certain heavy metal ions, hence accelerating the remediation process.

TABLE 1: The adsorption effect of different biochars on different heavy metals

Heavy Metals	Types Of Biochar	Adsorption Mechanism	Remark	Literature Source
Pb^{2+}	sludge biochar	Complex reaction with hydroxyl (-OH) and carboxyl (-COOH)	Adsorption rate: 38.2%-42.3%	[18]
		Precipitation and complexation	adsorption rate: 57.7%-61.8%	
	dairy manure	adsorption, ion exchange and precipitate with PO_4^{3-}, CO_3^{2-}		[9]
	dairy manure, rice straw	electrostatic adsorption, ion exchange	under the same condition: dairy manure＞rice straw	[19]
	peanut shell, Chinese medicine residue	ion exchange, electrostatic adsorption, complexation, the increase of pH make Pb^{2+} -carbonate bounded state transform into Pb^{2+}-insoluble phosphate and silicate state		[4]
Hg^{2+}	Brazilian pepper	complex reaction with hydroxyl (-OH) and carboxyl (-COOH)	pyrolytic temperature: low	[20]
		react with aromatic structure to form Hg-π	pyrolytic temperature: high	
	sugarcane, walnut wood chips	complex reaction with hydroxyl (-OH) and carboxyl (-COOH), ion exchange, electrostatic adsorption	under the same condition: sugarcane ＞ walnut wood chips	[21]

	Beanpoles	precipitation, forming $Hg(OH)_2$, $HgCl_2$		[22]
	crispus, Rice husk, Rice straws	complex reaction with hydroxyl (-OH) and carboxyl (-COOH),ion exchange	crispus is better when pH=5	[23]
Cd^{2+}	sugarcane leaves, tapioca stem, rice straw, silkworm excrement	electrostatic adsorption precipitate with CO_3^{2-},OH-	under the same condition: silkworm excrement＞rice straw ＞tapioca stem＞ sugarcane leaves	[24]
	maize straw	electrostatic adsorption,precipitation		[12]
Cu^{2+}	Biochar	complexation with functional groups	pH is 6-7	[25]
		to form $Cu_3(CO_3)_2(OH)_2$, CuO	pH is 8-9	
Cr(VI)	oak biochar	deoxidize Cr(VI) into Cr(VIII)		[26]
		complex reaction with hydroxyl (-OH) and carboxyl (-COOH)		
Cd^{2+}	sugarcane leaves, tapioca stem, rice straw, silkworm excrement	electrostatic adsorption precipitate with CO_3^{2-},OH-	under the same condition: silkworm excrement＞rice straw ＞tapioca stem＞ sugarcane leaves	[24]
	maize straw	electrostatic adsorption,precipitation		[12]
As^{5+}	pine needle, maize straw,	electrostatic adsorption	under the same condition: dairy	[27]

	dairy manure		manure＞pine needle ＞maize straw	
As^{3+}	maize straw	non-electrostatic physical reversible adsorption and chemical irreversible adsorption with polar groups	water solution	[28]
Ni^{2+}	Almond Putamina, reed straw	complex reaction with hydroxyl (-OH) and carboxyl (-COOH)	under the same condition: almond putamina＞reed straw	[29]
Zn^{2+}	Water hyacinth Hardwood	ion exchange,electrostatic adsorption		[1, 30]
Pb^{2+},**Cu^{2+}** Zn^{2+},**Cd^{2+}**	dairy manure	oxygenic functional groups and precipitate with PO_4^{3-},CO_3^{2-}	dairy manure has the best adsorption effect on four heavy metals, and among them, Pb^{2+} is most easily absorbed	[21]

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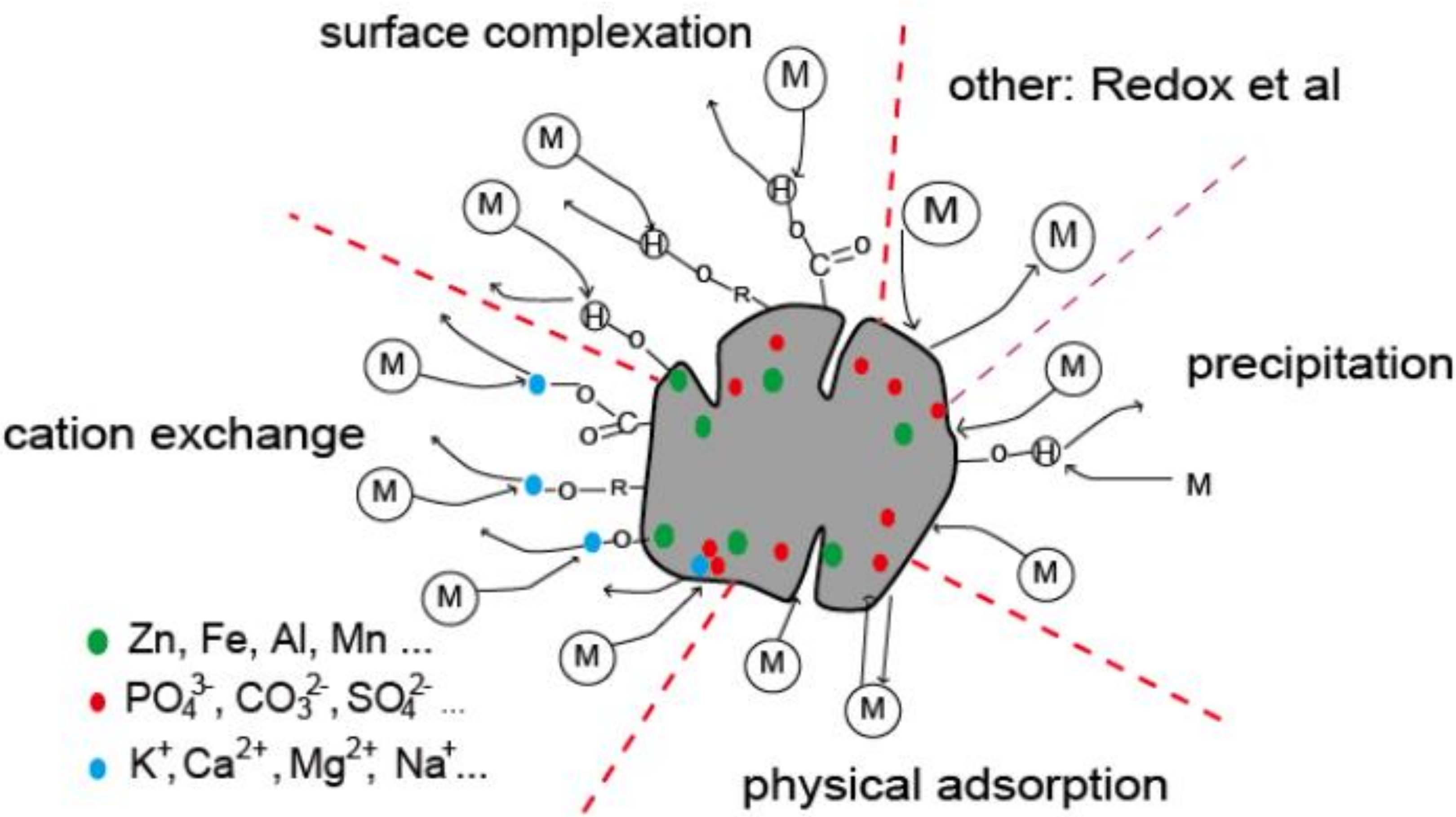

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According to studies, animal feces biochar has the highest adsorption capacity for Pb^{2+} (lead ions) among the three forms of biochar. This suggests that the removal of lead toxicity from the soil is a unique strength of animal waste biochar.

Multiple heavy metal ions, such as Pb2+, Cu2+, Zn2+, and Cd2+, may affect the way that biochar binds to heavy metals. David [31] and Xu [21] showed that when these ions coexist in the soil, the competitive adsorption of heavy metal ions might affect the overall adsorption result of biochar on heavy metals. Individual heavy metal ions' ability to bind to biochar surfaces depends on how they interact and compete with one another. When there are many heavy metal ions present, each metal ion may have a lower capacity for adsorption than it would have on its own. The overall efficiency of biochar in removing heavy metal pollutants may be impacted by the competition adsorption for few adsorption sites on the surface. With a rise in the initial concentration of heavy metal ions, competitive adsorption becomes more intense. Higher levels of heavy metal ions result in more ions vying for adsorption sites on the surface of the biochar. Therefore, when the starting concentration rises, the adsorption effectiveness of biochar for certain heavy metals may decline [32]. Pb^{2+} (lead ions) are often discovered to have the greatest adsorption ability with biochar among the examined heavy metals. This is due to both its reactivity with oxygenic functional groups and its capacity to form potent complexes with the phosphate (PO_4^{3-}) and carbonate (CO_3^{2+}) ions. Pb^{2+} interacts strongly with the surface functional groups of biochar due to its tiny hydrated ion radius and high electronegativity constant.

CONCLUSION

The use of biochar as a potential rehabilitation method for damaged soils caused by heavy metals is becoming more popular. Its ability to minimize the bioavailability of heavy metals, together with its high adsorption capacity and surface chemistry, make it a solution that is both effective and sustainable. However, in order to fully harness the potential of biochar, optimize its characteristics, and provide recommendations for its use in a variety of soil remediation situations, further study is required.

PROBLEMS AND ASPECTS

It has been established that biochar has an extraordinary adsorption impact on the pollution caused by heavy metals. It has come to everyone's attention that biochar has a significant influence on the adsorption of heavy metal pollutants. Because of its one-of-a-kind physical and chemical features, biochar has the capacity to efficiently adsorb heavy metal ions, hence lowering the bioavailability of these ions and minimizing the potential damage they may do to the environment. The mechanism involves ion exchange, cationic function adsorption, complexation with oxygenic functional groups to generate particular metal complexes on the surface of the biochar, electrostatic adsorption, precipitation, and other processes, but the predominant one is ion exchange. Animal waste biochar has greater significance than sewage and plant detritus biochar due to its abundance of charcoal and mineral components. In comparison to other heavy metals, biochar has the greatest adsorption effect on Pb^{2+} due to its physical and chemical properties. Animal feces biochar in particular has a promising future in the restoration of heavy metal-polluted soil, despite the fact that there are still some issues with its theoretical framework and future research plans. Several mechanisms are involved in the adsorption of heavy metals by biochar, including ion exchange, adsorption of cationic functions, complexation with oxygenic functional groups, electrostatic adsorption, and precipitation. These methods aid in the removal and immobilization of heavy metal pollutants by biochar. Biochar's adsorption capacity for lead ions (Pb^{2+}) is frequently the highest of all the studied heavy metals. This preference for Pb^{2+} may be due to its unique physical and chemical properties, such as its ability to form complexes with oxygenic functional groups and its interaction with its high electronegativity and minuscule hydrated ion radius. In addition, this preference may be a result of its ability to interact favorably with oxygenic functional groups.

The use of biochar in the removal of heavy metals from contaminated sites is now in the research phase in laboratories, and the likelihood of its immediate deployment on a broad scale in polluted areas is low at the moment. This suggests that further research and testing is required to prove its usefulness and perfect the procedures for using it. The method of applying biochar as a means of repairing heavy metal-polluted soil is now in the research phase in the laboratory, and the chance of its deployment directly into vast areas of contaminated sites is substantially less likely. In addition, there is not a single kind of biochar that will be able to solve the issue of heavy metal contamination all by itself. The ability of biochar to heal the damage caused by heavy metal pollution is significantly influenced by the kind of raw material used, the temperature at which the biochar is created during pyrolysis, its characteristics, and its cost. Therefore, in order to secure the successful use of biochar technology and the widespread use of it, we need to design the ideal "specific biochar" for concrete heavy metal contaminated soil in practical applications. This will allow us to assure the success of the deployment of biochar technology.

1. The texture, pH level, amount of organic matter, mineral make-up, and other features of the soil may vary greatly depending on the kind of soil. These characteristics have the potential to influence the adsorption behavior of biochar as well as the interactions that it has with heavy metal contaminants. To have a better understanding of how biochar functions in various soil types and the elements that determine its adsorption capability,

further study is required. Concerning the adsorption effect of biochar on heavy metal pollution, the influence of various kinds of soil, the competitive adsorption of heavy metal compound pollutions, the optimum pyrolytic temperature for biochar synthesis, and the complex soil conditions are not yet obvious.

2. There is a dearth of information about the regenerating cycle of biochar in soil, the manner in which its characteristics vary over time, and the ways in which it could damage the environment. In addition, the biochar material itself may include a minute amount of heavy metals; hence, it is essential that it be examined in advance to determine whether or not its use results in any unfavorable impacts.

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