Journal of Advanced Environmental Research and Technology

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Removal of Cd(II) from water sources using low-cost materials, modified low-cost adsorbents: A review

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Article info

Received 2024-08-26
Revised 2024-10-20
Accepted 2024-02-21

Abstract

In emerging countries, Cd(II) contamination is becoming a growing issue. Toxic to living things, cadmium(II) is an extremely dangerous metal. It is classified as a carcinogen by the International Agency for Research on Cancer (IARC) by the US Environmental Protection Agency (EPA), and strict limitations have been set for its presence in industrial effluent (which is released into cadmium-containing water bodies) and drinking water. The need for a cost-effective and efficient method to remove cadmium from water is urgent in underdeveloped countries. Waterways in developing nations have been increasingly contaminated with Cd(II) due to poor water and wastewater treatment and growing industrial activities. Water purification methods including membrane filtration, ion exchange, electrocoagulation, nanotechnology and activated carbon are ineffective in these countries due to the economic issues. Thus, substantial study has been done on inexpensive adsorbents to test their efficiency to remove cadmium from the environment. We focused on cost-effective adsorbents that can be used in the undeveloped countries, this review paper examines the current status of Cd(II) removal research. Two major kinds of adsorbents are examined in this review: different kinds of low-cost materials, and modified low-cost materials. This study also focused on the effects of various water-quality conditions on Cd(II) and these adsorbents, as well as their application in the removal of Cd(II).

Keywords

Cd(II)
low-cost materials

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DOI: ……..

1. Introduction

Freshwater is essential for both humans and wildlife to exist. Healthy people must have access to drinking water that is safe for consumption. Many types of pollution have degraded potential water sources around the world as water demand continues to rise (UN-Water, 2018). In addition to this, researchers have discovered that changes in the climate, Increased temperatures and changes in the water cycle, for example, will worsen these water-related problems, increasing floods and drastic droughts could occur as a result, and a rise in the toxicity of chemical pollutants in the atmosphere and environment. A polluted water sources can harm humans by exposing them to illnesses or toxic substances through the use of filthy water for irrigation, aquatic animals eating poisons, or people swimming in contaminated surface water. However, The most common cause of sickness for most people in emerging countries is drinking polluted water.

Increased pollution is a major problem in poor countries, where individuals lack the means to adequately remove toxins from the water supply or safe drinking water systems capable of providing water to the dwellings of their residents. Over 844 million people lack access to safe drinking water, according to the World Health Organization (WHO). This includes those who have access to improved sources, such as pipes, wells and protected wells and springs, as well as rainwater and packaged/delivered water . As a result of their inability to routinely access a better source of drinking water, people in undeveloped countries are more susceptible to water-borne diseases. Preventable water-borne diseases like as diarrhoea kill an estimated 1.6 million people each year, with children under five accounting for 90 percent of these deaths, according to WHO estimates. The greatest threat to human health in the developing world is contamination of drinking water by microbiological agents (e.g. bacteria and viruses). On the other hand, the rise in Cd(II) concentrations in drinking water is becoming an increasingly serious issue. Cadmium (Cd) is a hazardous non-essential transition metal that is harmful to people and animals. It is a contaminant that occurs naturally in the environment and is derived from agricultural and industrial sources. Exposure to cadmium occurs mostly through the consumption of contaminated food and water, but also through inhalation and cigarette smoking to a significant amount. Cadmium accumulates in plants and animals throughout a 25–30 year half-life. Cadmium features in emerging countries are shown in Table 1. According to the World Health Organization (WHO), the maximum contamination level of Cd(II) in drinking water is 0.003 mg L^{-1}.

Table 1
Characteristics of Cd(II).

Heavy metal	Human health effects	Common sources	Maximum Contaminant Level	
			USEPAa	WHOb
Cadmium (cd)	Kidney damage Carcinogenic	Naturally-occurring Various chemical industries	0.005 mg L-1	0.003 mg L-1

a Values established by the United States Environmental Protection Agency (USEPA, 2019).
b Values established by the World Health Organization.

With a rise in industrial and urban activity in recent years, heavy metal pollution has increased across the developing world. numerous enterprises' discharges of polluted sewage, including coalfired power plants and waste recycling and solid waste disposal activities is a significant source of pollution. Pollutant effluent from these sectors is composed of a variety of pollutants ranging from chemical to nutrient-rich pollutants. Dirty urban stormwater runoff, agricultural, and rainwater transit into potential drinking water sources all contribute to water contamination. Furthermore, underdeveloped countries, according to the United Nations, generate 80% of all industrial and municipal wastewater, which is then dumped directly into the environment without any prior treatment or filtration. Toxic and carcinogenic heavy metals are of special concern because of their known negative effects on human health. A further issue to be concerned about is heavy metal including cadmium contamination. This is because many of the water treatment technologies used in the developing world, are ineffective in removing heavy metals from the water.

It is common knowledge that drinking water in underdeveloped nations is polluted with heavy metals, which have been studied extensively in multiple review publications. As, Cd, and Pb, three of the most toxic heavy metals, were researched extensively for their public health consequences.

As a potentially harmful heavy metal, cadmium (Cd) is the third most frequently discovered in water supplies. In addition to being a non-essential trace element for humans, Cd(II) causes significant damage to the ecological 39 environment and to human health; food is one of the most significant sources of Cd(II) exposure in the general population [1]. Cd-contaminated drinking water was linked to chronic renal failure [2]; [3]. [4] Cd poisoning has been linked to renal failure in long-term exposure. Anemia, anosmia (loss of smell), cardiovascular disease, renal difficulties, osteoporosis, and hypertension are all possible side effects of long-term exposure to Cd [5]. Cadmium can cause anaemia by binding to ligands such as cysteine, glutamate, histidine, and aspartate [6]; [7]. It can cause both acute and chronic intoxications [8]. It is extremely harmful to the kidneys and builds up in the cells of the proximal tubules (e.g., bio-accumulative). [9] reported that either bone injury or renal failure can cause bone mineralization to occur. At low quantities, it can build up in the kidneys, causing kidney disease, bone fragility, and lung damage over a lengthy period of time [10]. Animal studies have revealed that the lungs absorb half of the Cd ingested, while the digestive tract only absorbs a small portion of the Cd [9]. [11] according to the study, Premature delivery and lower birth weights have been associated to maternal exposure to cadmium(II).

Trace metal contamination, which has the potential to be damaging to all living things, has long been a source of concern. because of its high toxicity and bioaccumulation, is growing more significant as industrialization progresses [12]; [13]; [14]. In terms of trace metals, Cadmium (Cd) is one of the most challenging to deal with since it is both toxic and persistent, and due to its mobility from the soil to the plants, where it can then be ingested by humans via the food chain [15]; [16]; [17]; [18]. Battery, electronic, and mining/metallurgical sectors account for the majority of the Cd that is released into the environment. This poisoning of water resources as well as the numerous consequences it has on terrestrial ecosystems are all due to these anthropogenic activities [19]; [20]; [21]. [22] research revealed that potatoes, rice and wheat are the main sources of Cd(II) absorption from soil and the resulting consequences on human bone health, including osteomalacia and osteoporosis. Water and soil contamination with cadmium causes the Itai-itai sickness in Japan, which is well recognised as a contributing factor [23].

in addition to the risks to human health posed by cadmium contamination [24]; [25]; [11]. There have been many investigations on the cadmium and other heavy metals pollution of water sources in underdeveloped nations by a number of scientists, including China [26]; [27], India ([2]; [28]; [29]; [30], Japan [5], Iran [31]; [32]; [33]; [34]; [35]; [36], Bangladesh [37]; [38]; [39]; [40], Ethiopia [41]; [42], Pakistan [43]; [44]; [45], and various other countries still in development [46]; [47]; [48]; [49]. In [50] study Cd(II) registered the highest pollution ranking among all heavy metals detected in the Nile river.

There has also been a lot of study done on ways to remove cadmium from industrial wastewater, municipal wastewater, drinking water sources, and other water sources because of the well-documented effects of cadmium on human health. Recently reviewed approaches and technology for cadmium removal that are currently under consideration in several developed nations include membrane and nano membrane filtration and ion exchange [51]; [52] [53], electrocoagulation [54]; [55]; [56]; [57]; [58], microbial remediation [59]; [60]; [61]; [62], activated carbon adsorption [63]; [64], carbon nanotechnology [65]; [66]; [67], and numerous adsorbents with different modifications [68]; [69]. Cadmium removal has been extensively studied in the past by experts from all over the world. Table 2 summarizes the many physical, chemical, and biological approaches for removing cadmium that have been investigated.

Table 2
Different cadmium removal methods

Method	Kind	Reference
Membrane Technology	Reverse osmosis (RO)	[70]; [71]; [72]
	Nano filtration (NF)	[71]; [73]; [74]
	Micellar enhanced ultra-filtration (MEUF)	[75]; [76]; [77]
	Polymer enhanced ultra-filtration (PEUF)	[78]; [79]
Solvent Extraction	Tributylphosphate and CYANEX 921	[80]
	Nitrate solution with a cationic extractant (MDEHPA)	[81]
Precipitation	Biological precipitation	[82]; [83]
	Chemical precipitation	[84]
Ion-Exchange	Ion exchange resin	[85]; [86]
Electrocoagulation (EC)	Direct current (DC) and alternating current	[87]; [88]; [89]
Flotation	Ion and precipitate flotation	[90]; [91]
	Sorptive and biosorptive flotation	[92]; [93]
	Hybrid flotation	[94]
Adsorption	Synthesized adsorbents	[95]; [96]; [97]

Activated carbon [98]; [99]

These technologies are not viable or cost-effective in underdeveloped countries, due to economic and scientific issues. The recommended methods for water treatment in underdeveloped countries must be simple to get, easy to build by local labour with minimum education, and inexpensive to operate and maintain.

The utilisation of low-cost, locally available materials that remove cadmium from water without the use of additional energy is the topic of this review study, as well as several low-cost materials modified chemically and physically (when the modification process and the chemicals used for modification have minimal environmental effects). There are many studies in the developing world on Cd(II) removal, but it is difficult to provide a comprehensive overview of those studies. Instead, the most regularly used and most readily available materials in poor countries will be the subject of this review article. There are six broad categories of materials that are examined in this review: Agricultural by-products, consisting of a variety of different sorts of leftover debris from nuts (such as pistachios and peanuts, etc.), in addition to organic waste products from fruits and vegetables (such as citrus peel, banana peels, beets, grapefruit, etc.); elements and compounds existed in the earth's crust (including minerals, clay, sediment rocks, and soil); different kinds of biomass (e.g., bisporus (mushroom), chlorella vulgaris, etc.); other various waste materials (e.g., black tea waste; Jatropha oil cake (JOC), etc.); physically modified low-cost adsorbents (e.g., sugarcane straw (dried and sieved), etc.); chemically modified low-cost adsorbents (e.g., KOH-activated douglas fir biochar, NaOH-treated juniper fiber, etc.). These materials were subjected to tests to determine their ability to remove Cd (II), and the hypothesised mechanisms for their removal were surveyed. To date, there has been minimal discussion of the use of low-cost materials to remove Cd(II) from water in peer-reviewed articles. A little more than three years have passed since the most recent review was released [100].

The influence of water quality variables on the elimination of Cd(II)

Adsorbent properties and cadmium (Cd(II)) behaviour should be examined under a variety of water quality situations when looking into the removal of Cd(II). There are a variety of possible interaction effects between different species in solution, and in particular, there are a variety of potential interactions on the surface that are dependent on the sorption mechanism. There are a variety of factors that influence the preference for a sorbet, including characteristics of the binding sites (e.g., functional groups, structure, surface properties), the properties of the sorbet (such as concentration, ionic size and charge, molecular structure, etc.), solution chemistry, and the sorbet's physical and chemical properties (e.g. pH, ionic strength, etc.) [101]. The pH, temperature, the presence of natural organic matter (NOM), and ionic strength are some of the most important water quality variables connected with the removal of Cd(II) from different kinds of water. While industrial effluent is the most prevalent source of Cd(II) contamination, there are other sources as well, numerous water sources, including domestic wastewater discharge, have been shown to contain the heavy metal in developing countries [102]; [103], groundwater [104]; [105]; [106]; [102]; [107]; [108], rivers [109]; [110]; [37]; [111]; [112] and lakes [113]; [46]; [114] [27]; [42]. Adsorbents' ability to remove Cd(II) contamination from these water sources is influenced by the water's quality parameters. Cd(II) and its removal will be discussed in the next sections, along with the impact of water quality on the chemistry of Cd(II).

Chemical characteristics of Cd(II)

As a result of numerous industrial activities, agricultural practises and poor waste disposal, Cd(II) enters the environment [115]. The environmental persistence of Cd(II) makes it a particular problem. Humans and animals are exposed to Cd(II) through the intake of contaminated food and water, where it accumulates since it is non-biodegradable. Extensive research was done on the health impacts of heavy metals such as Cd(II) [116]; [117]. Table 3 provides the chemical properties of Cd(II) found in the environment.

Table 3

Chemical Properties of Cd(II)

Heavy metal	Molecular weight (g mol-1)	Oxidation State(s)	Van der Waals radius (10-12 m)	Electronegativity (Pauling Scale)	Log KOW
Cadmium	112.4	+2	158	1.69	3.86 ∓ 0.36

Effect of pH

The concentration of Cd(II) and the properties of the metal depend critically on the pH of the water. The pH of aqueous solution has a major effect on the Cd(II) speciation in the solution. When Cd is in its cationic state, which is common at neutral to low pH levels, it is more soluble and mobile in water than when it is in its anionic state. Hydroxides and other anions in the water form complexes with a rising pH level. Cd(II) can also influence the adsorbent's surface charge, the concentration of ions on the adsorbent's functional groups, and the ionisation state of the adsorbent [118]; [119].

Studies have shown that pH has a significant impact on the speciation and removal of Cd(II). Cd(II) ions form complexes with hydroxide ions as the pH increases, influencing the oxidation state of Cd (II). It is common for Cd(II) to precipitate out of solution as the pH rises above neutral [118]. The presence of several distinct cadmium species, each with a different charge (for example, $Cd(OH)_2$), can be detected at various pH values [119]. Cadmium concentrations rise when the pH of the water supply is reduced, whereas when the pH is raised, immobilisation occurs predominantly as a result of precipitation [119]. In [120] study, Increasing the pH of the solution from 3 to 10 resulted in an increase in the removal of cadmium by adsorption on perlite, from 0 to 89% removal. When the pH was plotted against the amount of cadmium removed, there were two inflection points: one at pH 5, which was where considerable cadmium adsorption actually began, and another at pH 9, where the adsorption rose dramatically. The dramatic increase in cadmium removal (59–90 %) seen at pH 9 was most likely owing to the precipitation of cadmium ions as insoluble $Cd(OH)_2$precipitate, rather than adsorption [120].

As a result, water sources with low pH values (< 4.0) contain a large concentration of H+ ions, which might interfere with the interactions between soluble metal ions and adsorbent surfaces and so reduce the overall removal of cadmium from the water supply [121]; [122]. When the pH of the solution rises, on the other hand, the surface of the adsorbent becomes more negatively charged, which allows it to interact more readily with the positively charged heavy metals on the surface of the adsorbent [123]; [124]; [125]. Many different adsorbents have been used to investigate this phenomenon. [126] also expressed an increase in pH over pHzpc will result in a minor increase in adsorption as long as the metal species remain positively charged or neutral, even if the surface of the adsorbent is negatively charged, as long as the metal species remain positively charged or neutral. At low pH values (< 3.0), the adsorption of Cd(II) ions is ineffective [127]. At lower pH values, H+ ions compete with Cd(II) ions for the binding sites on the surface of the adsorbent's surface [128]. The lower pH causes a decrease in metal ion removal, which is thought to be owing to increased quantities of H+ present in the suspension, which compete with other ions for the adsorption sites of adsorbent. This shows that sorption from dilute hydrolysable metal ion solutions (such as those containing a heavy metal) happens at a pH that is lower than the pH at which hydrolysis takes place in most cases [129]. The effect of pH on cadmium sorption followed the expected metal sorption behaviour, with removal efficiency increasing as the pH of the solution increased, but decreasing as the pH of the solution increased above the equilibrium pH [129]. A crucial factor in cadmium's overall behaviour and elimination is pH; this can be summarised as "pH is a significant parameter" for Cd(II) removal. It has been proven that low pH levels (< 4.0) can limit cadmium adsorption while pH ranges between 5 and 7 have been shown to be the most effective, based on the published research that was reviewed. the pH of the water supply should be maintained at a neutral level in order to maximize cadmium adsorption in developing countries.

Effect of Temperature

Temperature is another key characteristic to consider when examining the behaviour of heavy metals and the eventual elimination of these metals from the environment. The effectiveness of several of the mechanisms for cadmium removal that have been found is increased when the temperature is raised, including surface complexation reactions and various forms of ion exchange [130]. To be more specific, the removal of cadmium (II) using Albizia lebbeck pods rose by around 22% when the temperature was raised from 30 to 80°C, which was attributed to the enhanced mobility of the cadmium, as well as the increased number of adsorption sites due to bond rupturing in a prior study [131]. Adsorption of Cd(II) onto coal and irvingia gabonensis seed shells increased with increasing temperature, according to another study, which was attributed to the potential increase in the shells' pores and to an increase in Cd(II) ions' kinetic energy, which allowed for more contact with the absorbent [132]. Because of the enhanced driving force of diffusion across the boundary layer and the accelerated diffusion rate within the adsorbent, higher temperatures have been found to accelerate the adsorption process in addition to increasing adsorption [133].

Increased temperatures, on the other hand, have frequently resulted in a decrease in the removal of cadmium from water. For instance, in one study, The removal of total cadmium by the indigenous clay was lowered from 80.3% to 51.3% with rising temperature from 30 to 50℃. The decrease in removal as temperature increases is due to the metal's enhanced solubility at comparatively high temperatures [134]. In one more study [135], the investigation revealed The removal percentage of cadmium reduced from 61.0 to 34.9 mg g-1 when the temperature was increased from 20 to 50℃. This result is typical for non-energetic metal biosorption, in which metal removal from solution occurs only through physico/chemical interactions between the biomass and the metal in solution. Temperature increase decreased the biosorption capability of biomass [135].

Moreover, in another study, when the temperature was raised to 45°C, a study on the adsorption of Cd(II) onto date pits found that the removal of Cd(II) increased, and then the removal decreased when the temperature was raised to 50°C. Possibly as a result of probable damage and deformation to the adsorption sites on the date pits, this result was achieved. [136]. In another study, the adsorption capacity of olive cake reduced by 32% when the temperature was elevated from 28 to 45°C, according to another study that assessed the removal of Cd(II) from olive cake using aqueous solutions [121]. [137] also showed that by increasing temperature from 298 K to 363 K, the absorbed of Cd2+ slightly decreased for both bagasse and olive stone. This behaviour revealed that low temperatures are advantageous for Cd2+ adsorption onto bagasse and olive stone and this could be because Cd2+ has a tendency to migrate from the solid phase to the bulk phase when the temperature of the solutions increases [137]. Because of this, while evaluating the impacts of temperature on the removal of cadmium, it is necessary to examine each adsorbent and the corresponding concentration of cadmium ions separately in order to identify the overall influence of temperature changes on the adsorption process.

Effect of ionic strength

It has also been discovered that the ionic strength of the water supply has an effect on cadmium and its ability to be removed from water. When chloride is present, it is possible to produce cadmium-chloride complexes that are both soluble and difficult to remove [138]. Observations of this phenomena were made by by [139], who found that the removal effectiveness of Cd(II) decreased significantly as the ionic strength increased. They concluded that this was due to the increasing production of cadmium-chloride complexes with a poor affinity for the adsorption. According to the findings of the study, an increase in salinity is associated with an increase in the concentration of cadmium in estuaries. [140].

The elimination of cadmium can be affected by the ionic strength of a solution when electrostatic forces are heavily influencing interactions between cadmium and other surfaces. Electrostatic interactions are influenced by theories relating to surface chemistry, and when ionic strength increases, an electric double layer lowers, resulting in reduced cadmium adsorption [141]. For example, An investigation into the effects of ionic strength on the removal of cadmium by bentonite [141] found that the overall removal of cadmium reduced as the ionic strength increased. [142] also reported that the sorption of Cd(II) on biochar decreases as the ionic strength increases in the low pH range. According to [143], the removal of Cd(II) decreased by approximately 50% as the ionic strength of the solution increased from 0.0 to 0.5 M NaCl, due to an increase in the concentration of Na^+ and Cl^-, which result in a steric hindrance and compete with cadmium ions for surface vacant sorption sites on the surface of the adsorbents. Moreover, a study on the adsorption of Cd(II) onto ferromanganese binary oxide–biochar composites demonstrated that Cd(II) adsorption capacities of FMBC were not dramatically influenced by ionic strength [144].

Effect of Natural Organic Matter (NOM)

Natural organic matter (NOM) has been shown to change in both quality and quantity, posing issues for water treatment systems. While NOM is not harmful in and of itself, its presence in water increases biological development in distribution networks, binds to contaminants, and regulates the bioavailability of trace metals. Although NOM contains a variety of functional groups, the carboxyl and phenolic groups are the most abundant, as they have a high affinity for metals depending on the pH [145]. Humic and fulvic acids are generated through the decomposition of plant and animal waste, and are usually thought to be the constituents of natural organic matter (NOM) [146]; [147]; [148]. NOM is a complex mixture of organic acids that exhibits high reactivity with cadmium when exposed to it [147]. It is widely acknowledged that humic and fulvic acids are chemically heterogeneous substances capable of interacting with the surface of biosorbents, altering their physicochemical properties and thus affecting their sorption behaviors [149]; [150]. Interactions between NOM and cadmium have been observed, and these interactions have the potential to modify the reactivity of cadmium in the environment [147]. It is believed that the presence of adsorbed humic compounds has a significant impact on the fate, bioavailability, and movement of metal ions in water and soil [151]; [152]. This is owing to the large number of additional parameters that influence the manner in which NOM affects cadmium, including pH, the humification of the specific NOM, and the oxidation state of , which can make it difficult to determine its exact impact on cadmium [153]. When HA is adsorbed to mineral surfaces, it has the ability to slow the movement of metal ions. In contrast, HA in soil solution can form soluble complexes with these ions, hence increasing the solubility of the ions in solution [151]. Consider the discovery that cadmium forms compounds with both humic and fulvic acids, which may lead to enhanced cadmium immobilisation in soils and water [154]; [155]. [156] reported that the presence of organic matter slightly enhances the removal of Cd(II) by mollusk shells. These results suggest that NOM can have an unpredictable impact on the removal of cadmium and that this can make it more difficult to identify the prevalent processes involved with cadmium removal in the future. [157] also showed the effect of NOMs on heavy metal adsorption on modified argillaceous limestone, FAL. As for the presence of humic acid (HA), the adsorption of Cd2+ by FAL adsorbent increased with increasing the HA concentration. In another study, [158] demonstrated that due to the interaction between the negatively charged humic acid and the positively charged cadmium oxide, cadmium ion adsorption to the cadmium oxide in the complex is increased relative to that on the isolated oxide, whereas adsorption to the humic acid in the complex is decreased relative to that on the isolated humic acid [158].

Removal of Cd(II) using low-cost materials

Agricultural by-product

Researchers in both industrialised and developing countries have extensively studied the removal of Cd(II) using agricultural waste. Cd(II) removal from water in underdeveloped countries is often facilitated by the use of agricultural waste as a source of inexpensive, abundant adsorbents. In the developing world, for example, rice residue trash is a common type of agricultural waste that is produced in vast quantities. Rice bran, rice straw, and rice husk are all examples of this sort of waste. It has been demonstrated that these waste products are effective at removing Cd(II) from aqueous solutions. Rice husk is an agricultural waste product that accounts for approximately one-fifth of the world's yearly gross rice production, or 545 million metric tonnes (Ye, Zhu, & Du, 2010). Rice husk includes a high concentration of floristic fibre, protein, and functional groups such as carboxyl, hydroxyl, and amidogen, all of which are necessary for the adsorption processes to take place [159]. The ability of natural and modified rice husks to remove Cd(II) ions from water was investigated. The results indicated that the natural and modified rice husks had an adsorption capacity of 73.96 and 125.94 mg g-1, respectively [160]. The increased number of adsorption sites and exchangeable sites available for adsorption can be attributed to the increased number of exchangeable sites accessible for cd(II) adsorption [161]; [162]. Various fruit and vegetable wastes such as fruit peels, fruit shells have been shown to effectively remove Cd(II) from aqueous solutions. For instance, a banana peel was utilised in one study to remove Cd(II) from environmental and industrial effluent, despite the fact that it is a routinely produced fruit waste. In order to explain partitioning behaviour for the system operating at room temperature, the Langmuir adsorption isotherm was utilised. Compared to previously other reported materials, the value of qm was found to be (35.52 mg g-1) greater [163]. In the course of this sorption experiments, it was discovered that the amount of Cd(II) bound had been reduced from 99 to 0 %. The reduction in the % sorption on esterified banana peel suggested that –COOH groups were involved in the selective sorption of Cd on the surface of the peel (II) [163]. In another stufy banana peel also exhibited varying degrees of Cd(II) removal in aqueous solution, It was demonstrated in 2009 by [122] that the adsorption capacity of Cd(II) was 34.1 mg g-1, demonstrating considerable removal of Cd(II). lemon peel was shown to effectively Cd(II) achieving maximum adsorption capacities of 54.6 mg g-1 [122]. Orange peel also demonstrated effective Cd(II) removal in a variety of studies [164]; [165]; [166]. Using orange peel, researchers [122] investigated the adsorption of Cd(II) and found that it could be removed significantly, with maximum adsorption capacities of 41.8 mg g-1. The researchers found that the peel could remove significant amounts of Cd(II) and that it could remove significant amounts of Cd(II). The removal of Cd(II) from orange peel was demonstrated in another investigation, with a maximum adsorption capacity of 293 mg g-1 achieved by utilising chemically modified orange peel [167]. In one study [168] The adsorption properties of four agricultural wastes, litchi peel (LP), orange peel (OP), pomegranate peel (PP), and banana peel (BP), were. The highest adsorption capacities of LP, OP, PP, and BP were 230.5, 170.3, 132.5, and 98.4 mg g-1, respectively. The four peels had the following adsorption capacities for Cd (II): LP>OP>PP>BP. According to the absorption peaks, the banana peel adsorbent comprises –C=C, –CH, and –C–O. These results indicate that the four peels contain a high concentration of oxygenated surface groups, which can be used to bind metallic ions such as Cd (II) [168] Peel particles also have folds, ravines, or a lamellar structure on their surfaces, which considerably enhances the contact area between the adsorbent and the adsorbate and hence boosts the adsorption capacity of the peel particle [168]. Pomelo peel has also been shown to have the ability to remove Cd(II), with a maximum adsorption capacity of 21.83 mg g-1 [169]. Biosorption capacity was consistently greater at pH 5 than at pH 3 in this investigation. This is most likely because the proton concentration at pH 5 decreased, reducing competition between protons and cadmium ions for the same binding site [170]. To conclusion, peel adsorbents have a diverse chemical makeup; the adsorption reaction can involve a range of chemical groups on the surface [171]. At the moment, the mechanism of action of peel adsorbents for heavy metal ions is unknown. Due to the complicated chemical composition of peel, the adsorption process may involve a number of different mechanisms. Numerous investigations have established that adsorption occurs via ion exchange, complexation, chelation, chemical precipitation, and surface adsorption, among others [172]. Furthermore, investigations demonstrated that these mechanisms frequently coexist [173]. Peel adsorbents contain a variety of functional groups, including –COOH, –OH, –OCH3, –NH2, –CONH2, and –SH, as well as polyphenols, lipids, and amino acids. These functional groups can interact in a variety of ways with heavy metal ions [168]. Additional vegetable waste has been demonstrated to be effective at removing Cd(II) from water sources. Numerous active and inactive microbial biomasses have been employed as biosorbents for heavy metal ions due to their high content of organic ligands or functional groups (–COOH, –OH,–SH, –NH2, –CONH2, –OCH3, SO_4^{2-}, PO_4^{3-}) that are essential for the removal of a range of heavy metal pollutants [174]. Biosorbents include, but are not limited to, fungi, yeast, algae, bacteria, and agricultural waste [175]. For instance, mushrooms, which are classified as macrofungi, have been explored for their potential to remove Cd(II) by adsorption [125]. In one study, P. ostreatus mushroom harvested from a farm and its leftover substrate after harvesting were tested for Cd(II) sorption capacity [176] in batch studies in order to determine the most effective biosorbent and the most favourable circumstances for the removal of heavy metals from wastewater. The maximum adsorption capacity for P. ostreatus mushroom harvested from a farm and its leftover substrate after harvesting were determined 19.86 and 18.42, respectively [176]. In this study [176], based on the results of the SEM-EDX and FTIR characterization, it was discovered that the biosorption process was carried out by an ion exchange process in addition to complexation by functional groups on the biosorbent surface . After Cd(II) biosorption, the modification of peaks due to carboxyl, hydroxyl, amide, and C–O, C–O–C, or phosphate groups indicates that these groups were involved in metal adsorption [176]. It has also been demonstrated that corncob may remove Cd(II) from aqueous solutions. [124] discovered a maximum adsorption capacity of 5.1 mg g-1 when they investigated its removal of Cd(II). When natural corncob was oxidized with citric acid (CA) or nitric acid (NA), the adsorption capacity of the corncob was raised by 10.8 and 3.8 times, respectively, compared to when the corncob was not oxidized. The Cd(II) ions were primarily adsorbed to carboxylic sites, since the adsorption capacity increased linearly with the carboxylic site concentration in the corncob [124]. On Table 4, you will find an overview of selected studies that evaluated the ability of agricultural by-product to remove Cd(II). In recent years, a number of detailed review papers have been published that cover the removal of Cd(II), and other pollutants, with agricultural by-products used as adsorbents [177], [178].

Table 4 Removal of Cd(II) by various agricultural by-products.

Adsorbent	Heavy metal	Surface area (m2g-1)	C0 (mg L-1)	qmax (mg g-1)	Reference
Banana peel	Cd(II)	1.3	100-800	34.1	[122]
Coconut-shell biochar	Cd(II)	212	100-2000	3.5	Paranavithana et al. (2016)
Litchi peel (LP)	Cd(II)	NA	25-1000	230.5	[168]
Orange peel (OP)	Cd(II)	NA	25-1000	170.3	[168]
Pomegranate peel (PP)	Cd(II)	NA	25-1000	132.5	[168]
Banana peel (BP)	Cd(II)	NA	25-1000	98.4	[168]
Corncob	Cd(II)	< 5	5-150	5.1	[124]
Grapefruit peel	Cd(II)	NA	50	42.1	[179].
Lemon peel	Cd(II)	1.3	100-800	54.6	[122]
Orange peel	Cd(II)	NA	50-1200	293	[167]
	Cd(II)	2.0	100-800	41.8	[122]
Rice husk	Cd(II)	NA	50-200	16.6	[123]
Natural rice husk	Cd(II)	NA	20-800	73.96	(Ye, Zhu, & Du, 2010)
S. Lychnophera Hance	Cd(II)	NA	0.25-1.0	27.1	Liu et al. (2006)
Sugar cane bagasse	Cd(II)	0.49	10-30	0.96	Moubarik and Grimi (2015)
Solanum elaeagnifolium	Cd(II)	NA	NA	18.94	T.H. Baig et al (1999)
dragon fruit peel	Cd(II)	NA	10-100	7.469	[180]
Jatropha fruit coat	Cd(II)	NA	25-250	21.97	[181]
Jatropha seed coat	Cd(II)	NA	25-250	22.83	[181]
Pomelo peel	Cd(II)	NA	25-100	21.83	[169]
Radish (Raphanus sativus) peels	Cd(II)	NA	1-100	19.8	[182]
Sweet potato peels (PTPS)	Cd(II)	1.91	50-500	18.9	[183]
Sunflower (Helianthus annuus)	Cd(II)	NA	0.5-300	14.9	[184]
Canola	Cd(II)	NA	0.5-300	14.7	[184]
Walnut Shell	Cd(II)	NA	0.5-300	8.3	[184]
Moringa olifera	Cd(II)	NA	1-100	1.06	[185]
Petiolar sheath palm	Cd(II)	NA	5-100	10.8	[186]
Cashew nut shell	Cd(II)	395	10-50	22.11	[161]
Ceiba pentandre hulls carbon	Cd(II)	NA	40-100	19.5	[187]
Compost of fruits and vegetables	Cd(II)	NA	5-60	5.43	[188]
Papaya wood	Cd(II)	NA	5-500	17.22	[189]
Rice polish	Cd(II)	NA	100-150	9.72	[190]
Wheat bran	Cd(II)	403	10-15	0.703	[191]
Broad bean peel	Cd(II)	NA	5-1000	147.71	[192]
Medlar peel	Cd(II)	NA	5-1000	98.14	[192]
Peas peel	Cd(II)	NA	5-1000	118.91	[192]
Fig leaves	Cd(II)	NA	5-1000	103.09	[192]
Maize corncob	Cd(II)	NA	5-500	105.6	[193]
Eucalyptus bark	Cd(II)	NA	25-300	14.53	[194]
Grape bagasse	Cd(II)	0.4979	0.5-600	0.774	[195]
Styrax leaves	Cd(II)	NA	0.5-10	0.72	[196]
Plum leaves	Cd(II)	NA	0.5-10	0.71	[196]
Walnut leaves	Cd(II)	NA	0.5-10	0.65	[196]
Styrax + Plum leaves	Cd(II)	NA	0.5-10	0.71	[196]
Neem bark	Cd(II)	3.47	3-100	25.57	[197]
Saw dust	Cd(II)	3.85	3-100	26.73	[197]
Mungbean Husk	Cd(II)	NA	10-500	35.41	[198]
Egeria densa	Cd(II)	NA	4-8 mEq/L	1.28 mEq/g	[199]
Jordanian jojoba	Cd(II)	NA	25	9.89	[200]
Bamboo charcoal	Cd(II)	1120	20-150	18.20	[201]
Coconut copra meal	Cd(II)	NA	40-140	1.84	[202]
Hazelnut shell	Cd(II)	NA	10-200	5.45	[203]
Almond shell	Cd(II)	NA	10-200	3.40	[203]

Areca waste	Cd(II)	80	4-12	1.12	[204]
Cassava waste	Cd(II)	NA		18.05	[205]
Pine park	Cd(II)	NA	0-2 mmol/L	14.16	[206]
Albizia lebbeck pods	Cd(II)	34.07	10-30	7.81	[131]
Cashew nut shell	Cd(II)	395	10-50	22.11	[207]
Date pits	Cd(II)	NA	4-90 ppm	6.5	[136]
Pleurotus ostreatus mushroom	Cd(II)	NA	0-400	19.86	[176]
Pleurotus ostreatus mushroom spent substrate	Cd(II)	NA	0-400	18.42	[176]
Peganum harmala seed	Cd(II)	NA	2.5-50	1.765	[208]
Prosopis farcta seed	Cd(II)	NA	2.5-50	4.610	[208]

Elements and compounds existed in the earth's crust (including minerals, clay, sediment rocks, and soil)

The removal of cadmium from aqueous solutions by soil and other mineral deposits has been the topic of numerous investigations. Hazardous elements such as cadmium have varying degrees of affinity for soil and mineral deposits, which are heterogeneous in nature. In many cases, the solubility (Ksp) of the cadmium is attributed to the variability in their affinity for the metal. This can result in the precipitation of metal carbonates and hydroxides, and other physical and chemical properties of the cadmium, such as charge density, electronegativity, and the hydrolysis constant (pKH), can also contribute to the variability in their affinity for the metal [209]. Using soils and other natural materials to remove Cd(II) from aqueous solution may be an appropriate and effective solution for developing countries because of the economic and technological constraints they face. For example, [209] evaluated the potential of three distinct soils from Puerto Rico to remove cadmium from the environment. Various soils were investigated, and the maximum adsorption capacities varied from 1.6 to 3.5 mg g-1 for different kinds of soils studied. Cd(II) was removed by each soil tested with different adsorption capacity. Research by [210] found that Cd(II) could be removed from peat by employing two types of peats. When it came to adsorption, Cd(II) was the best medium for all three types of peat, with capacities ranging from 32.0 to 50.2 mg g-1 at their highest. Carboxylic, hydroxylic, and phenolic groups in peat have been shown to contribute to Cd(II) adsorption, which explains the high removal rates of Cd(II) by peat [210].

Following the recognition of the crucial role played by oxyhydroxides in trace metal sorption in natural aquatic systems, numerous adsorption models have been developed to account for this phenomenon [211]. Cd(II) removal from drinking water may be possible using mineral deposits containing manganese-oxyhydroxides, which might be employed as a filter material, although reducing circumstances in a filter system must be avoided in order to prevent Mn-oxides from being reductively dissolved and the sorbed cd(II) from being mobilized [212]. Cd(II) adsorption capabilities of 32.0 mg g-1 were reached using these deposits. When imported synthetic adsorbent is prohibitively expensive, impoverished countries can save money by using locally available natural adsorbents like different kinds of rock. The feasibility of employing phosphate rock as an adsorbent for the removal of Cd(II) from aqueous solutions was explored by [101]. In their study, the phosphate rock(PR) achieved maximum adsorption capacity was 10.46 mg g-1. Ionic radius and Pauling electronegativity have been used to rank affinity in the context of sorption on apatite, among other things [213]. Cd(II) exhibited intermediate behaviour due to its small ionic radius of 0.97 A° and high electronegativity [101]. The adsorption capacity of activated phosphate rock(APR) was 31 % higher than that of untreated phosphate rock, according to the scientists [101]. The untreated phosphate rock showed a maximum adsorption capacity of 10.46 mg g-1, but the activated phosphate rock showed 13.56 mg g-1 for cadmium removal [101]. In another study, the maximum adsorption capacity of Cd(II) on vermiculite was obtained 79.9 mg g-1 [214]. In this study, The capacity of vermiculite to adsorb Cd(II) was improved by increasing the pH and temperature of the solution. The initial impact was ascribed to electrostatic interactions and competition for cationic sites between protons and Cd(II). The second trend revealed that adsorption occurred at an endothermic process [214] and the adsorption of Cd(II) on vermiculite is mainly due to the mechanisms of ion exchange and electrostatic attraction [214]. A selection of studies that demonstrate the potential of soil and mineral deposits to remove cadmium are presented in Table 5.

Table 5 Removal of Cd(II) by elements and compounds existed in the earth's crust (including minerals, clay, sediment rocks, and soil).

Adsorbent	Heavy metal	Surface area (m2g-1)	C0 (mg L-1)	qmax (mg g-1)	Reference
Mn-oxyhydroxide mineral	Cd(II)	143	0-225	32.0	[212]
Peat (Danish)	Cd(II)	13.3	225	50.2	[210]
Peat (Heilongjiang)	Cd(II)	9.7	225	32.0	[210]
Phosphate rock	Cd(II)	13.5	10-500	10.46	[101]
Soil (Entisols)	Cd(II)	28.5	100-2000	3.4	Paranavithana et al. (2016)
Soil (Mollisols)	Cd(II)	17.3	134.9	3.0	[209]
Soil (Oxisols)	Cd(II)	41.9	134.9	1.6	[209]
Soil (Ultisols)	Cd(II)	37.8	134.9	3.5	[209]
Perlite	Cd(II)	NA	1	0.64	[215]
Magnesite	Cd(II)	NA	600	4.20	[216]
Manganese nodule residue	Cd(II)	NA	100-500	19.8	[217]
Phosphate rock (PR)	Cd(II)	13.5	0-150	10.46	[218]
Loess soil	Cd(II)	24.1	25-150	9.37	[219]
Scoria	Cd(II)	NA	0-2 mEq L-1	21.49× 10-3 mmol g-1	[220]
Gisenyi volcanic rock	Cd(II)	3	1-50	6.23	[221]
Virgin volcanic rocks- Pumice	Cd(II)	NA	0.5-50	-	[222]
Gypsum rock	Cd(II)	NA	10	18.332	[223]
Pyrite	Cd(II)	NA	20-500	174	[224]
Ball clay	Cd(II)	NA	0.1-50	27.17	[225]
Kaolinite	Cd(II)	20.1819	50-150	7.407	[226]
Metakaolinite	Cd(II)	33.8331	50-150	9.174	[226]
Vermiculite	Cd(II)	15.2	0-350	79.9	[214]
Limestone	Cd(II)	NA	10-50	1.46	[227]
Chabazite	Cd(II)	73.61	10-50	120	[228]
Turkish illitic clay (TIC)	Cd(II)	3.10	50-1200	13.09	[229]

Different kinds of biomass

Using soils and other natural materials to remove Cd(II) from aqueous solution may be an appropriate and effective solution for developing countries because of the economic and technological constraints they face. [230]. When it comes to cadmium removal from water and wastewater, MO outperforms the competition (removing more than 90% of the cadmium). [231]; [230]. Additionally, researchers have shown that the application of MO has no significant influence on the characteristics of the source water (e.g., pH, ionic strength), in addition to the removal of Cd(II) [231]; [230]. MO removal has been postulated by a variety of methods, including adsorption, charge- neutralization, complexation, and interparticle bridging [231].

Another material that has been extensively examined for its adsorptive properties is sawdust. Numerous studies have established that sawdust from a range of trees is a good method for removing cadmium. beech sawdust effectively removed Cd(II) [232]. Additionally, sawdust from poplar and linden trees removed Cd(II) in variable degrees [233]; [232]. Lignin is another biomass material that has been extensively explored for its potential to be utilised to remove Cd(II) from water. Lignin is a naturally occurring polymer present in the cell walls of plants. Lignin is a plentiful, highly aromatic byproduct of the paper-making industry with a poor utilisation rate that has the potential to be used as a feedstock for the production of biochar [234]. Lignin typically accounts for 16 to 33% of plant biomass. Paper companies throughout the world have produced more than 50 million tonnes of lignin over the course of their history [235]. Several investigations have demonstrated that lignin is an excellent cadmium remover [236]. Furthermore, as the pyrolysis temperature is raised, the adsorption capacity of the lignin increases dramatically [234]. Researchers have indicated that the presence of carboxylic and phenolic functional groups in lignin makes it easier to remove Cd(II) from water. These functional groups have been shown to interact strongly with Cd(II), making them potentially suitable locations for Cd(II) adsorption [235]. In addition, a number of review papers on the adsorption of Cd(II) have been published in recent years.Which fosused on utilising lignin and other lignocellulosic materials in conjunction with these specific research [237]; [238]. Aquatic biomass, such as seaweed [239]; [240] and algae [241]; [242], has also been proven to be successful in the removal of cadmium from a range of water sources, including drinking water. Utilizing brown (A. nodosum), red (C. crispus), and green (C. vermialara) algae, a team of researchers [243] investigated the removal of Cd(II) using a wide range of combinations and systems. Even when they were investigated in varied combinations, efficient removal of Cd(II) (more than 90%) was accomplished in each case. A research of the removal of Cd(II) from seawater using brown, red, and green seaweeds revealed a wide variety of adsorption capabilities that varied depending on the species of seaweed utilised. A total of 17.9 to 82.9 mg g-1 of maximal adsorption capacity was found in brown seaweeds, brown seaweeds are the most effective, and red seaweeds are the least effective, in that order. [244]. It has also been demonstrated that the roots of water hyacinths may remove Cd(II), with maximal adsorption capability of 70.3 mg g-1 [245]. In several situations, changes and other treatments have been investigated to increase the removal of Cd(II) by biomass, which we will be discussed in the following. Table 6 provides an overview of selected research investigating the ability of different kinds of biomass to remove cadmium from the water and wastewater, as well as their findings.

Table 6 Removal of Cd(II) by different kinds of biomass.

Adsorbent	Heavy metal	Surface area (m2g-1)	C0 (mg L-1)	qmax (mg g-1)	Reference
A. Bisporus (mushroom)	Cd(II)	NA	10-100	29.7	[125]
A. Nodosum (brown algae)	Cd(II)	NA	10-150	69.7	[246]
Banana peels biomass	Cd(II)	< 5	50-500	121.3	[247]
Cauliflower leaves biomass	Cd(II)	12.5	50-350	73.8	[247]
C. Indica (mushroom)	Cd(II)	NA	10-100	24.1	[125]
C. Vermilara (green algae)	Cd(II)	NA	10-150	21.4	[246]
Padinasanctae-crucis algae	Cd(II)	30.73	80	93.45	[248]
H. Splendens (moss)	Cd(II)	NA	10-400	32.5	[249]
Juniper bark	Cd(II)	NA	29.2	8.6	[250]
Chlorella vulgaris	Cd(II)	11.98	10-120	97.43	[251]
Ulva lactuca	Cd(II)	NA	20-30	8.804	[252]
Ulva fasciata	Cd(II)	NA	20-30	8.353	[252]
L. hyperborea	Cd(II)	NA	75-100	31.3	[253]
S. muticum	Cd(II)	NA	75-100	38.4	[253]
F. spiralis	Cd(II)	NA	75-100	42.1	[253]
B. bifurcata	Cd(II)	NA	75-100	30.3	[253]
Juniper wood	Cd(II)	NA	29.2	3.2	[254]
P. Platypus (mushroom)	Cd(II)	NA	10-100	35.0	[125]
S. Lychnophera Hance	Cd(II)	NA	0.25-1.0	27.1	[255]
Padina sp.	Cd(II)	NA	46	84.30	[256]
Sargassum sp.	Cd(II)	NA	46	85.43	[256]
Ulva sp.	Cd(II)	NA	46	65.20	[256]
Gracillaria sp.	Cd(II)	NA	46	33.72	[256]
Carnauba fruit biomass	Cd(II)	NA	25-250	34	[257]
Cattail biochar stem	Cd(II)	7.631	5-30	66.756	[258]
Cattail biochar root	Cd(II)	15.758	5-30	18.808	[258]
Cattail biochar leaf	Cd(II)	7.243	5-30	44.215	[258]
Peat moss	Cd(II)	NA	10-400	39.8	[259]
water hyacinth	Cd(II)	NA	100-500	70.3	[245]
Caulerpa fastigiata (Macro algae)	Cd(II)	NA	30.29-101.87	16.48	[260]
blue algae-derived biochars	Cd(II)	15.75	0-1000	135.7	[241]
Fomitopsis pinicola	Cd(II)	NA	10 mM	103.2	[261]
Dolochar	Cd(II)	81.6	10-50	1.9	[262]
Anabaena sphaerica	Cd(II)	NA	50-300	111.1	[263]
C. Crispus (red algae)	Cd(II)	NA	10-150	65.2	[246]
Valisneria spiralis	Cd(II)	NA	15, 30	0.098	[264]
E. crassipes	Cd(II)	NA	15, 30	0.082	[264]
P. stratiotes	Cd(II)	NA	15, 30	0.083	[264]
Calotropis procera	Cd(II)	NA	5-500	40	[265]
cork waste biomass	Cd(II)	NA	0-1 mM	2.13 mol/g	[266]
Lucerne biochar	Cd(II)	NA	0-100	6.28	[267]
Sargassum wightii		NA	50-200	38.8	[268]
Caulerpa racemosa	Cd(II)	NA	50-200	10.4	[268]
Agaricus bisporus macrofungus	Cd(II)	NA	50-245	3.49	[269]
Live oscillatoria sp. H1	Cd(II)	NA	25-250	32.2	[270]
Ceramium virgatum	Cd(II)	NA	0-300	39.7	[271]

Rivularia bulata algae [272]	Cd(II)	NA	11.2-489.1	26.36	
Chlamydomonas reinhardtii [273]	Cd(II)	NA	20-400	42.6	
Oedogonium sp.	Cd(II)	1.22	100-200	88.2	[274]

Other waste material

A lot of study has been done to see if local waste material can be used to remove Cd(II) from aqueous solutions effectively. Different types of rubbish may be generated in greater quantities than others as a result of differences in local environments, energy sources, farming practises, and civilizations, among other factors. The production of tea in India, for example, amounts to around 857,000 tonnes per year [275], As a result, a significant amount of tea is wasted away. Countries such as India and China, who rely largely on coal for their energy needs, are also confronted with massive volumes of coal combustion waste products such as coal ash, which must be dealt with. The adsorptive characteristics of tea trash have been investigated in a variety of experiments conducted over the last two decades. Cd(II) can be successfully removed from tea trash, according to a study [276] [277]. [276] tested the removal of cadmium, In an experiment with a simulated watery solution and brewed tea trash as a possible adsorbent, the adsorption process explained by the Langmuir isotherm had a monolayer adsorption capacity for Cd(II) ions of 2.468 mg g-1. Coal fly ash, which is a common by-product of fossil fuel burning and is a solid waste produced in coal combustion [278], has been demonstrated to be effective at removing Cd(II) from aqueous solution in several studies. [279] showed that In the optimal conditions, the removal efficiency and adsorption capacity of Cd^{2+} by caol fly ash was were 95.76% and 31.79 mg g−1, respectively. The electrostatic attraction between the Cd(II) and the charged surface of the adsorbent was attributed to this phenomenon. In another study [280] showed that the removal of Cd(II) using coal fly ash achieved maximum adsorption capacity of 19.89 mg g-1. Several review articles on the usefulness of coal fly ash as an adsorbent have been published in last decades [278]; [281]; [282]; [283]; [284]; [285]. Aqueous solutions including shells from several aquatic species have been proven to be effective at removing cadmium from them. According to the findings of [286], the freshwater mussel shells biosorbent displayed the following maximum adsorption capacity according to the Langmuir equation: 18.2 mg g-1 at 10°C < 26.0 mg g-1 at 30°C< 28.6 mg g-1 at 50°C. There was significant elimination of Cd(II) from the environment by the ground surf clam shells, obtaining the highest possible adsorption capacity of 633.3 mg g-1 from the ground surf clam shells [287]. While that for scallop shells were found to be effective in the removal of Cd(II), with the highest adsorption capacity of 195.8 mg g-1 [287]. There have been several publications on the efficiency of shells from diverse aquatic species as an adsorbent in the last few years [288]; [289]. Other waste products that are easily available in the local community have been evaluated for their ability to remove Cd(II) from aqueous solutions and the results indicate that they are effective. Coffee residues discarded from instant coffee production were examined for their adsorptive capacities for the removal of Cd(II) by [290]. the pyrolyzed coffee residues and clay, showed the maximum adsorption capacity 39.5 mg g-1, according to the results of this investigation [290]. In another work [291], the potential of spent coffee grounds (SCGs) as a substitute adsorbent for the removal of cadmium (Cd) from aqueous solutions was investigated. The maximal Cd(II) adsorption capacity of the SCGs was determined to be 19.32 mg g-1 in this investigation. Adsorbents for cadmium removal, such as coffee residues, have been studied extensively during the last few decades [292]; [293]; [294]. It was discovered in 2003 that cocoa shells have adsorptive qualities by measuring the removal efficiency of a Cd(II) in a multi-solute solution [295]. According to the findings of this investigation, the maximum adsorption capacity was quite low (0.18 mg g-1). In another study using cocoa shells as an adsorbent for Cd(II) removal, [296] found the maximum capacity of 4.508 mg g-1 for Cd(II) adsorption by cocoa shells. Neem oil cake, which is a waste product obtained from the fruit of the Neem (A. Indica) plant, has been demonstrated to be effective in the removal of Cd(II) from the environment. Oil cakes in general, have low C/N ratio. Therefore their degradation is rapid and this is an additional advantage that spent oil cakes are degraded rapidly and hence their disposal is easy in comparison to other biosorbents [297]. In the mentioned study, the maximal adsorption capability for Cd(II) was found to be 11.8 mg g-1 by the researchers [297]. The removal of Cd(II) from aqueous solutions by tobacco dust has also been demonstrated. It was reported that [129] used lignocellulosic agricultural residues, namely tobacco dust, to reduce Cd(II) in water and found that it had the highest adsorption capacity of 29.6 mg g-1. From the surface acidity and electrokinetic property data, it can be hypothesized that the process of biosorption of the cadmium onto the tobacco dust is largely governed by metal-proton ion exchange and electrostatic attraction under general sorption pH settings (pH 4–7). Under higher pH circumstances, hydroxide precipitate adsorption could also occur, besides metal–proton ion exchange and electrostatic attractions. and the removal of Cd(II) is primarily due to the high cadmium binding capacity by proton replacement as well as its negative surface charge throughout a wide pH range, all of which led to the removal of the Cd(II) by the tobacco dust [129]. It was discovered that utilising olive cake, which is a waste product of olive oil production, it was possible to effectively remove Cd(II). The greatest adsorption capacity was 65.4 mg g-1, and the investigation indicated that this was the maximum adsorption capacity [121]. In another study, the adsorption of cadmium on Phosphogypsum, a by-product of the phosphate fertiliser industry, was investigated. The maximum adsorption capacity of lime-preconditioned phosphogypsum was determined to be 131.58 mg g-1. Table 7 contains a summary of selected research examining the potential of other waste materials to remove cadmium, as well as a list of the studies themselves.

Table 7 Removal of Cd(II) by other various waste material.

Adsorbent	Heavy metal	Surface area (m2g-1)	C0 (mg L-1)	qmax (mg g-1)	Reference
Black tea waste	Cd(II)	192	5-100	13.8	[277]
Coal fly ash	Cd(II)	14.20	10-250	31.79	[279]
Coal fly ash	Cd(II)	10.2	20-80	19.0	[280]
Cocoa shells	Cd(II)	NA	28.1	0.18	[295]
Coffee residues	Cd(II)	6.48	25-250	39.5	[290]
Neem oil cake	Cd(II)	NA	10-100	11.8	[297]
Olive cake	Cd(II)	NA	100	65.4	[121]
Olive stone	Cd(II)	0.38	10-30	0.93	Moubarik and Grimi (2015)
Oyster shells	Cd(II)	NA	0-300	118	[298]
Razor clam shells	Cd(II)	NA	0-300	501	[298]
Tobacco dust	Cd(II)	NA	0-50	29.6	[129]
Sugar beet pulp	Cd(II)	NA	NA	24.39	Z. Reddad et al (2002)
Eggshell waste	Cd(II)	NA	60-200	111.1	[299]
Brewed tea waste	Cd(II)	NA	100	2.468	[276]
Jatropha oil cake (JOC)	Cd(II)	NA	5-500	86.96	[193]
Esterification wood pulp	Cd(II)	NA		4.9	[300]
Phosphogypsum	Cd(II)	6.228	0-6	131.57	[128]
Turkish tea waste (fibrous)	Cd(II)	21.2	1-100	11.29	[301]
Clarified sludge	Cd(II)	NA	0-65	36.23	[302]
Morus alba L.	Cd(II)	NA	50-1000	21.69	[303]
Saw dust	Cd(II)	3.85	0-120	26.73	[304]
Cement kiln dust	Cd(II)	NA	384.55-1825.8	92.3539	[305]

Modified adsorbents

An actual challenge in the current situation is to create an excellent adsorbent out of agricultural waste plant components. As adsorbents, this type of agricultural waste material is suitable for use in water remediation because of its low cost, rapid regeneration, and high efficiency. [306]. cadmium ions are easily adsorbable because of their porous nature and wide specific surface area. The carbon content of activated carbon derived from plant-based adsorbents is high, whereas the inorganic content is low [307]; [308]. Activated carbon or raw plant-based adsorbents can reduce waste disposal costs and offer an environmentally friendly alternative, but their adsorption effectiveness, stability, and recyclability must be improved before they can be utilised commercially.

Physical modification

Different physical techniques such as autoclaving, cutting, grinding, thermal drying, milling, boiling, carbonization, and steaming can be used to modify plant-based adsorbents. These operations alter the particle size and surface area of the adsorbent [309]. As shown in Table 8, the use of physically modified plant-based adsorbents for cadmium removal is discussed. Phragmites australis adsorbent, after being dried and modified with a screen, demonstrated the highest adsorption capacity of 5.41 mg g-1 [310]. [311] showed that crushed of walnut shell had the maximum adsorption capacoty of 7.29 mg g-1 in cadmium removal efficiency.

Table 8 Removal of Cd(II) using physically modified low-cost adsorbents.

Adsorbent	Heavy metal	Surface area (m2g-1)	C0 (mg L-1)	qmax (mg g-1)	Reference
Sugarcane straw (Dried and Sieved)	Cd(II)	35.5	0.5-5	8	M. Farasati et al (2016)
Walnut shell (Crushed and Sieved)	Cd(II)	NA	20-200	7.29	[311]
Phragmites australis (Dried and Sieve)	Cd(II)	23.5	0.5-5	5.41	[310]

Chemical modification

For the purpose of removing soluble organic compounds, pretreatment methods involving various modifying agents such as base solutions (sodium hydroxide, calcium hydroxide, sodium carbonate), mineral and organic acid solutions (hydrochloric acid, nitric acid, sulfuric acid, tartaric acid, citric acid, thioglycollic acid), organic compounds (ethylenediamine, formaldehyde, epichlorohydrin, methanol), oxidizing agent (hydrogen peroxide) can be used to modify [312]; [313]; [314]; [315] low-cost adsorbents in a variety of ways to achieve desired results. Chelating efficiency, surface area, and porosity are all improved as a result of these chemistries, which either oxidize surface functional groups or introduce new functional groups to the biosorbent surface. When rice husk is subjected to chemical modification, such as hydrochloric acid [316]; [317], sodium hydroxide [317], sodium carbonate [318], tartaric acid [319]; [320], or epichlorohydrin [317] hemicellulose, lignin, or excessive cellulose crystallinity is removed, resulting in increased porosity and surface area, which improves adsorption capacity over unmodified rice husk. [321]. Meanwhile, the majority of the acids utilized for low-cost adsorbents treatment were dilute in nature, such as sulfuric acid, hydrochloric acid, and nitric acid [321]. In one study, a comparison of the two sorbents' adsorption capacities revealed that modified orange peel had a greater Cd adsorption capacity of 11.2 mg g-1 than original orange peel, which has a capacity of 6.94 mg g-1 [322]. According to the research, because the active binding sites for metals are believed to be hydroxyl and carboxyl functional groups in cellulose, chemical modification has showed tremendous promise in increasing the cation exchange capacity by increasing the number of functional groups [322]. Thus, protonation of orange peel with 0.1N HNO_3 is used to remove excess cations such as calcium or sodium that may interfere with metal sorption and to create a more defined sorbent material that enhances heavy metal binding by reducing competition between different ions such as K^+ and Ca^{2+} and heavy metal ions such as Cd^{2+} [322]. In another study, The adsorption effectiveness for cadmium ions was found to be 4.6 times larger in the modified orange peel adsorbent than in the untreated orange peel [323]. Morover, another study showed that NaOH-Fe^{2+}modified rice straw exhibited higher performance and showed an increase in adsorption capacity from 24.77 mg g-1 to 406.46 mg g-1, which was 16 times that of the original rice straw biochar. The study also showed the specific surface area of original rice straw biochar was 241.93 m2/g, 179 times lower that of NaOH-Fe^{2+}modified rice straw (1.35 m2/g) [324]. In another study [325] reported that KOH-modified Ipomoea fistulosa showed higher performance and showed an increase in adsorption capacity from 55.5 mg g-1 to 72.43 mg g-1. The study also demonstrated the specific surface area of 350°C Ipomoea fistulosa was 27.5 m2/g, which is 24 times lower that of KOH-modified Ipomoea fistulosa (650 m2/g). [326] done a research for the removal of Cd(II) ions from aqueous solutions using chemically modified pine barks (Pinus nigra). In this article effects of chemical modification methods on the adsorption capacity have been investigated for different kinds of activation, Including NaOH and HCl activation. Reseach reported that the adsorption capacity of Cd(II) ions were obtained with the values of 3.49 mg g-1 when HCl modification was implemented, and 13.76 mg g-1 for the NaOH modification. For the adsorption of toxic metal cations, adsorbent surfaces must be charged negatively. Acid modification decreased the organic content of adsorbent, but in this study, expected increase of adsorption did not appear comparing with NaOH modification due to decreased porosity and positively charged surfaces with H^+ ions [326]. [327] investigated the potential of the Citric Acid Modified Moringa oleifera Leaves powder (CAMOL) in removing Cd(II). In this study the maximum adsorption capacity found 171.37 mg g-1 for Cd(II) removal, which presumed that mainly due to the active groups such as hydroxyl groups (−OH) and carboxylic groups (COO−) [327]. There is a Table 9 that summarises selected studies on the efficacy of chemically-modified low-cost adsorbents to remove cadmium.

Table 9 Removal of Cd(II) using chemically modified low-cost adsorbents.

Adsorbent	Heavy metal	Surface area (m2g-1)	C0 (mg L-1)	qmax (mg g-1)	Reference
KOH-activated Douglas Fir biochar	Cd(II)	1049	25-1000	29.0	[328]
Grafting modification of corncob biochar using acrylonitrile	Cd(II)	0.95	20-200	85.65	M. Luo et al (2018)
Grafted copolymerization-modified orange peel	Cd(II)	NA	50-1200	293.3	[323]
NaOH-modified biomass of Solanum elaeagnifolium	Cd(II)	NA	NA	18.63	T.H. Baig et al (1999)
Ultrasonic-assisted dragon fruit peel	Cd(II)	NA	10-100	24.76	[180]
NaOH-treated juniper fiber	Cd(II)	0.2450	0-1000	29.54	[329]
NaOH-modified dairy manure biochar	Cd(II)	9.40	0-250	68.08	[330]
NaOH and HNO_3-activated phosphate rock	Cd(II)	22.5	0-150	13.56	[218]
NaOH-treated spent grain	Cd(II)	NA	0-300	17.3	[331]
polyacrylic acid-modified Esterification wood pulp	Cd(II)	NA		168	[300]
NaOH-Fe^{2+}modified rice straw	Cd(II)	1.35	500	406.46	[324]
KOH-modified Ipomoea fistulosa	Cd(II)	650	10-50	72.43	[325]
Na_2HPO_4-treated bamboo	Cd(II)	NA		202.7	[332]
NaOH-modified Auricularia Auricular matrix waste	Cd(II)	NA	50-150	47.62	[333]
NaOH-modified oil shale ash	Cd(II)	NA	0-100	12.05	[334]
NaOH-modified banana stalks	Cd(II)	NA	0-300	5.815	[335]
NaOH-modified sunflower	Cd(II)	NA	0-300	14.281	[335]
NaOH-modified corn cob	Cd(II)	NA	0-300	19.862	[335]
NaOH-modified hickory biochar	Cd(II)	NA	10-100	53.6	[336]
HNO_3-modified banana stalks	Cd(II)	NA	0-300	6.738	[335]
HNO_3-modified sunflower	Cd(II)	NA	0-300	16.282	[335]
HNO_3-modified corn cob	Cd(II)	NA	0-300	18.461	[335]
H_2SO_4-modified banana stalks	Cd(II)	NA	0-300	5.210	[335]
H_2SO_4-modified sunflower	Cd(II)	NA	0-300	12.742	[335]

H2SO4-modified corn cob	Cd(II)	NA	0-300	13.891	[335]
H3PO4-modified Enteromorpha prolifera biochar	Cd(II)	1204	0-300	423	[337]
H2SO4-modified pineapple fruit peel biomass	Cd(II)	NA	50-200	42.10	[338]
NaOH-modified pine bark	Cd(II)	3.15	0-60	13.76	[326]
HCl- modified pine bark	Cd(II)	1.18	0-60	3.49	[326]
Citric acid- Moringa oleifera leaves powder	Cd(II)	NA	10-1000	171.37	[327]
NaOH-modified saw dust (SD) of Alstonia macrophylla	Cd(II)	NA	0-70	54.522	[339]

3Conlusionsy

Aqueous solution cadmium removal is one of the most critical environmental concerns facing today, with a global impact. Researchers have worked on various techniques to produce a cadmium-free environment and to comply with the severe requirements set forth by various government agencies. They are continuously working on ways to obtain more cost-effective and efficient results. Adsorption by low-cost adsorbents is one of the most reliable methods in today's world for undeveloped countries. This method can also be used in these countries with some simple modifications to improve adsorption efficiency, improving adsorption capacity during the cost-effective activation procedure.

Water treatment technologies that would remove cadmium from drinking water and industrial wastewater are not readily available in emerging countries. Therefore, a substantial amount of research has been performed into the use of low-cost adsorbents to remove cadmium from water sources due to this development. These include various types of agricultural by-products, elements and compounds existed in the earth’s crust (including minerals, clay, sediment rocks, and soil), different kinds of biomass and other various waste material, physically modified low-cost adsorbents, chemically modified low-cost adsorbents, and other low-cost adsorbents that have been investigated. According to researchers' findings, these materials are good at removing cadmium. However, chemical changes to adsorbents boosted the overall adsorption capabilities of the examined materials, although these techniques are generally hard to available to adopt in emerging countries.

It is important to note that the effectiveness of these materials in removing cadmium is greatly influenced by the pH, ionic strength, and temperature, as well as the features of the material such as specific surface area.

The common water and wastewater treatment technologies such as membrane technology, solvent extraction, precipitation, ion-exchange, electrocoagulation, flotation, adsorption with synthezied adsorbents and activated acrbon, etc. are not viable or cost-effective in underdeveloped countries, due to economic and scientific issues. The recommended methods for water treatment in underdeveloped countries must be simple to get, easy to build by local labour with minimum education, and inexpensive to operate and maintain.

Using low-cost adsorbents, which are feasible and locally available materials that can remove cadmium from water without the use of additional energy, as well as low-cost materials modified chemically and physically (when the modifications have a minimal environmental impact) was the subject of this review study. These materials can be integrated into a water treatment process with just a little technology and skill in the poor world. These materials are widely available in developing countries..

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