Enhancing Heavy Metal Removal from Wastewater Using Low-Cost Adsorbents: A Review

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***Abstract*—Heavy metals are significant contaminants in wastewater, posing a serious threat to the environment and human health due to their non-biodegradable nature and ability to accumulate in living tissues. This issue is particularly relevant in the context of wastewater generated from domestic, industrial, and agricultural sources. Among these, the industrial and agricultural sectors are primary contributors to heavy metal discharge into water bodies. Therefore, finding cost-effective methods to remove heavy metals from wastewater is of utmost importance. Adsorption emerges as a promising wastewater treatment technique, valued for its cost-effectiveness and availability. This review article aims to consolidate scattered information on the use of low-cost adsorbents for heavy metal removal from wastewater, categorizing them into natural, industrial, and agricultural waste-based adsorbents. Initially, the article briefly discusses the sources of wastewater generation and highlights the adverse effects of heavy metals on human health when present in water. Subsequently, it delves into the application of low-cost adsorbents as effective means of removing heavy metals from wastewater. Finally, the article explores factors influencing the adsorption capacities of these selected low-cost adsorbents and presents methods for enhancing their adsorption capabilities.**

Keywords—Adsorbents, heavy metal, wastewater, adsorption

I. INTRODUCTION

Water, indisputably the planet's most vital resource, finds itself increasingly imperiled in the face of escalating global development. The persistent rise in water pollution levels not only engenders a shortage of potable water but also begets widespread suffering for a multitude of individuals worldwide. Over the years, the quality of water has deteriorated mainly due to anthropogenic activities, population growth, unplanned urbanization, rapid industrialization, and unskilled utilization of natural water resources [1]. Wastewater often contains harmful pathogens, chemicals, heavy metals, and various other contaminants that can pose serious health risks to human health if they are released into the environment without any treatment. Furthermore, untreated wastewater can have detrimental effects on aquatic ecosystems. So, treating wastewater before it contaminates the surface and groundwater bodies is essential. According to Manasa & Mehta [2] identifying sources of wastewater and its polluting components is essential to save water bodies. The same authors explained that domestic, agricultural, and industrial sectors are the major sources of generating wastewater. Among the significant contaminants in wastewater, heavy metals take a prominent place. Kuldeyev et al [3] explain that the numerous industrial operations, such as fuel and energy generation, iron and steel production, metallurgy, and metal surface treatment, generate waste materials laden with diverse heavy metals. Furthermore, Evans et al [4] described that water pollution has increased due to the use of chemicals including pharmaceuticals for agricultural activities. In most of the countries, discharging standards for water quality parameters have been introduced to prevent water pollution. Regrettably, in several nations, these byproducts are still discharged into the environment without undergoing subsequent treatment.

The escalating global concerns surrounding water pollution have necessitated innovative and cost-effective solutions for enhancing the removal of heavy metals from wastewater. Heavy metals, such as lead, cadmium, chromium, and mercury, are notorious pollutants known for their adverse health effects on both humans and the environment. The increasing anthropogenic activities, urbanization, and industrialization have amplified the discharge of heavy metals into our water bodies, posing a grave threat to water quality and ecosystem health.

This article's main goal is to comprehensively review recent research published on Google Scholar from 1998 to 2023 regarding the utilization of low-cost adsorbents for wastewater treatment, with a primary focus on removing heavy metals. It seeks to provide a detailed summary of these research findings. Additionally, this review delves into the literature to examine the removal efficiencies of various heavy metals using different low-cost adsorbents, the treatment techniques employed, and the chemical properties of these adsorbents. Moreover, the article addresses the key limitations associated with using low-cost adsorbents in wastewater treatment and briefly outlines future directions for incorporating low-cost materials into wastewater treatment systems.

II. HEAVY METALS IN WASTEWATER

Heavy metal is one of the most important pollutants present in the wastewater. According to Tripathi and Ranjan [5] heavy metals present in the wastewater are persistent and non-biodegradable and can be easily absorbed by living cells. Furthermore, they explained that there exists a group of metals, approximately 20 in number, (Pb, Hg, Cd, As, Cr, Tl, Be, Ba, Ra, U, Pu, Ni, Zn, Cu, Ag, Au, Pd, Co, Mn, and Fe) that exhibit high persistence and are resistant to degradation or destruction. These metals, such as Mercury (Hg), Lead

(Pb), Cadmium (Cd), Chromium (Cr [VI]), Zinc (Zn), Arsenic (As), Nickel (Ni), among others, are considered toxic heavy metals from an ecotoxicological standpoint. So, the presence of heavy metal ions in water is very harmful to life [6]. The consumption of contaminated water with heavy metals results in serious human health issues such as cardiovascular disorders, neural damage, renal injuries, risk of cancer, and diabetes.

Zinc (Zn) is a vital heavy metal for human health as it plays a crucial role in regulating various biological processes within the body. However, excessive concentrations of Zn can lead to severe health issues such as skin irritation, nausea, and anemia. Similarly, an excess of copper (Cu) in the body can result in symptoms like vomiting, convulsions, and even fatalities. Elevated levels of nickel (Ni) can lead to serious lung and kidney problems, while a high concentration of mercury (Hg) can weaken pulmonary and kidney function. Lead (Pb) is another heavy metal that poses health risks, damaging the kidneys, liver, and reproductive system. To prevent these health hazards, it is imperative to remove heavy metals from wastewater before they contaminate surface and groundwater resources [7]. The discharge of untreated wastewater containing heavy metals is a significant environmental threat and a health risk to humans. It is imperative to reduce or completely eliminate harmful metal levels in wastewater before their release into the environment [8]. Various methods have been explored for the removal of heavy metals from wastewater, including electrocoagulation, magnetic field techniques, membrane filtration, and adsorption [9]. Among these approaches, numerous studies have emphasized the use of low-cost adsorbents for heavy metal removal due to their cost-effectiveness and ease of implementation.

III. Adsorption

Adsorption is considered a more efficient and economical approach in comparison to alternative technologies for treating wastewater and removing heavy metals. It is the process by which a liquid solute forms a molecular or atomic film on the surface of a solid adsorbent (the adsorbate). Adsorbents can be categorized into three groups: synthetic, natural, and semi-synthetic [10]. The absorption process can be described using two types physical adsorption and chemical adsorption depending upon the intermolecular attractive forces. Physical adsorption refers to a mechanism whereby the adsorbate molecules are bound to the surface of an adsorbent through the influence of van der Waals forces of attraction. In chemical adsorption, the strong interaction between the adsorbate and the substrate surface creates new types of electronic bonds (Covalent, Ionic) [5]. When there exists a disparity in concentration between the substance being adsorbed (adsorbate) and the material it is adhering to (adsorbent), the adsorbate molecules in the solution migrate and attach themselves to the surface of the adsorbent [10]. By now, the adsorption process is widely used for identifying the applicability of various adsorbents to remove multiple pollutants from wastewater by identifying the removal efficiencies for relevant adsorbates. According to Raj et al, (2019) there are several mathematical models to describe the kinetics of adsorption. These models are used to describe the kinetic process of adsorption and the adsorption mechanism [11]. Furthermore, adsorption isotherms are used to investigate the mechanics of adsorption[12]. The equilibrium between the adsorbed and unabsorbed concentrations at a particular temperature is described by an adsorption isotherm [13]. Langmuir isotherm model and the Freundlich isotherm model are the widely used isotherm model for investigating the adsorption mechanisms of adsorbents [12].

IV. Low-Cost Adsorbents and Their Applicability to remove Heavy Metals

Low-cost adsorbents, encompassing natural materials, industrial wastes, and by-products, have emerged as a viable and cost-effective solution for treating wastewater contaminated with heavy metal pollutants. Researchers in the past have frequently turned to low-cost materials, either in their natural state or after suitable modifications, for wastewater treatment.

A. Natural Adsorbents

When contemplating natural adsorbents for wastewater treatment, they have garnered considerable attention as cost-effective alternatives worth investigating. Among these natural adsorbents, natural zeolite stands out as a well-established and economically viable option. Zeolites exhibit exceptional proficiency in the removal of cadmium (more than 80%) due to their composition, consisting of hydrated aluminosilicate minerals formed by interconnected tetrahedral structures of alumina (AlO_4) and silica (SiO_4) moieties [14]. Natural zeolites can be further enhanced through various methods, including acid treatment, ion exchange, and surfactant functionalization. These modifications substantially augment their adsorption capacity, particularly for organic substances and anions. Moreover, several researchers have explored the remarkable capacity of human hair to effectively eliminate heavy metals from wastewater. For instance, Asubiojo and Ajelabi[15] conducted a study revealing that human hair exhibited impressive removal efficiencies for heavy metals such as zinc (Zn), lead (Pb), iron (Fe), and manganese (Mn), with removal rates ranging from 64.3% to 92.4%.

Additionally, biosorbents have emerged as cost-effective and environmentally friendly materials for wastewater treatment in previous studies. Ghasemi et al.[16] conducted research in which they utilized Sargassum hystrix algae, sourced from the Persian Gulf coastline in Bushehr, Iran, as a biosorbent to extract Fe (II) from aqueous solutions. Furthermore, the capacity of cuttlebone to adsorb lead (II) and copper (II) from aqueous solutions was identified, specifically focusing on the dead biomass of cuttlefish bone. The results demonstrated the significant potential of cuttlebone for self-purification in marine environments and its efficiency as a medium for removing metal ions from water and wastewater. This underscores its promise as an adsorbent for both Pb^{2+} and Cu^{2+} ions. Notably, cuttlebone exhibited maximum adsorption capacities (qm) of 45.9 mg/g for Pb^{2+} and 39.9 mg/g for Cu^{2+}, highlighting its effectiveness in metal ion adsorption [17]. Furthermore, it is worth noting that natural red earth and peat have been recognized as highly efficient and cost-effective adsorbents for the removal of lead (Pb) from landfill leachate, as demonstrated by Abhayawardana's research in 2015[18]. This finding underscores the practical and sustainable potential of these materials in mitigating the environmental impact of wastewater contaminants.

B. *Industrial Wastes*

When examining industrial wastes, it's important to note that they encompass the byproducts and residues generated during various manufacturing and production processes across industries. This review paper primarily focuses on industrial wastes resulting from construction and demolition activities. Building waste materials, such as Portland cement, fine and coarse aggregates, and admixtures like fly ash and plasticizers, exhibit a notable capacity for the removal of heavy metals. Additionally, roof waste and brick and mortar waste, containing clay, have demonstrated high adsorption capacities for heavy metals. One particularly noteworthy industrial waste is fly ash, a by-product of coal combustion. Researchers have been exploring its potential as a cost-effective method for wastewater treatment. For instance, Maiti et al[19] reported a remarkable 93.8% removal efficiency for copper at an initial concentration of 43 mg/L and a pH of 6, using a fly ash dosage of 63 g/L. Similarly, Hegazi[20] found that fly ash exhibited high removal efficiencies for multiple inorganic pollutants when dosed at 60 g/L, highlighting its effectiveness. Moreover, Maiti et al.[19] pointed out that fly ash is particularly well-suited for treating acidic wastewater generated by industries such as electroplating, fertilizer production, copper smelting, and acid mine drainage. Detailed information regarding selected industrial wastes for heavy metal treatment in wastewater can be found in Table 1.

C. *Agricultural Wastes*

Agricultural wastes refer to the byproducts and residues generated within the agricultural sector during various farming activities and crop production processes. These wastes encompass a diverse array of materials, including crop residues, animal manure, agricultural runoff, and discarded packaging materials. In past research, agricultural wastes have been extensively employed in wastewater treatment processes. Specifically, materials such as peanut skin, wheat bran, paddy husk, bagasse, and coconut coir pith have found widespread application in the removal of heavy metals from wastewater. Table 1 depicts detailed information on the applicability of low-cost adsorbents for heavy metal removal from wastewater highlighting their adsorption capacities, removal efficiencies, treatment techniques, and chemical properties of the adsorbents by categorizing them as natural adsorbents, industrial wastes, and agricultural wastes. The utilization of such low-cost adsorbents presents a promising avenue for the development of efficient and economical strategies for wastewater treatment and environmental protection.

After reviewing these past researches, it's clear that almost all the low-cost materials showed a good removal efficiency for Pb. Notably, zeolite and brick clay have exhibited outstanding 100% removal efficiency for Pb, while several other selected low-cost adsorbents have demonstrated impressive removal efficiencies for Pb (Table 1). Additionally, clay mineral adsorbents have been widely used for heavy metal removal processes due to their higher adsorption capacities. Furthermore, natural and agricultural adsorbents such as peanut skin, wheat bran, paddy husk, human hair & bagasse showed higher removal efficiencies for heavy metals (Zn, Pb, Fe & Mn) and their removal efficiencies varied from 64.3 to 97.8%, 45.0 to 93.5%, 64.3 to 91.7%, 64.3 to 92.4% and 62.5 to 98.5% respectively[15]. Column experiments and batch sorption experiments have emerged as the predominant methodologies for assessing the efficacy of adsorption as a treatment process. In response to the pressing global environmental concerns associated with industrial wastewater, researchers have increasingly focused their efforts on the treatment of heavy metals within this particular category of wastewater. This emphasis on heavy metal treatment stems from the substantial environmental impact that industrial wastewater can have on a global scale.

Moreover, a significant trend observed among researchers is the enhanced adsorption capacity of modified low-cost materials compared to their natural counterparts, particularly in the removal of heavy metals. For instance, Nhapi et al. [21] found that activated rice husk (ARH) consistently exhibited superior removal efficiencies for heavy metals such as Pb, Cd, Cu, and Zn when compared to carbonized rice husk (CRH).

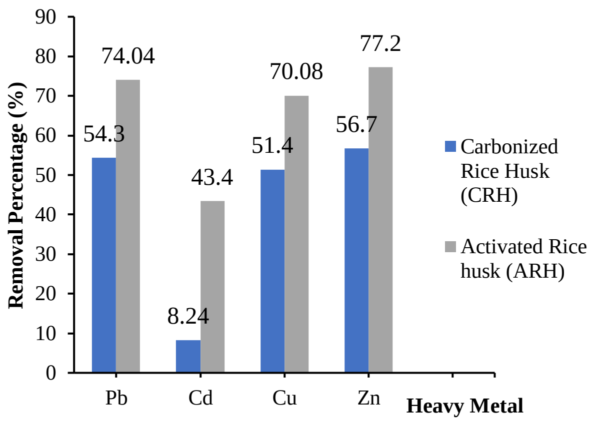

Fig. 1: Comparison of heavy metal removal efficiencies between CRH & ARH

Fig. 1 provides a visual representation of the comparative removal efficiencies for Pb, Cd, Cu, and Zn between ARH and CRH. This trend underscores the potential of modified low-cost materials as promising alternatives for efficient heavy metal adsorption and it illustrates that ARH consistently outperforms CRH in terms of removal efficiencies for relevant heavy metals. Furthermore, thermally modified zeolite exhibits superior heavy metal removal efficiencies compared to natural zeolite, which displays lower removal rates in comparison.

V. Influential Factors in the Adsorption of Heavy Metals onto Adsorbents

The efficiency of heavy metal adsorption by various low-cost adsorbents is influenced by several key factors. These factors encompass the particle size distribution, the duration of contact between the adsorbent and the metal ions, the temperature at which the adsorption process is conducted, the pH level of the solution, the initial concentration of metal ions in the solution, and the adsorbent dosage. In most cases adsorption capacities of adsorbents increase when particle size reduces because reducing the particle size leads to an increase in the surface area of the adsorbent material, which in turn enhances the contact area available for interactions with the target molecules in the wastewater.

A. *Effect of Contact Time*

Effect of contact time is one of the most important characteristics that affects the adsorption process. The main objective of obtaining optimal contact time is to identify the best contact time for the adsorption of relevant parameters onto the adsorbent. Optimum contact time varies depending on the type of the adsorbent and the adsorbate. Normally after the optimum contact time is achieved, there cannot be a significant change of the equilibrium concentration. As examples, Desta (2013) identified the optimum contact time for the removal of heavy metals using agricultural wastes. At initially adsorption rate was increased rapidly for all the heavy metals (Ni, Cd, Cu, Cr, Pb), and after 60 min removal efficiencies were reached to an equilibrium value[22]. Adsorption of Cd (II) onto bentonite was studied by Chen et al (2011) and observed that within the first 10 min 95% of fast adsorption showed by bentonite. The optimum contact time was captured with 1h and after that it reached equilibrium concentration[23]. Similarly, Chen et al. (2011) investigated the adsorption of Cd (II) onto bentonite. Their study revealed that within the first 10 minutes, bentonite exhibited rapid adsorption, with 95% of the adsorption occurring during this period. The optimal contact time was determined to be 1 hour, after which the concentration of Cd (II) in the solution reached equilibrium [23].

B. *Effect of Temperature*

Numerous researchers have explored the influence of temperature on the removal of heavy metal concentrations. For instance, Vinayakamoorththy (2019) observed that the total iron removal capacity, when recycling building waste, increased with higher temperatures [24]. In another study, Desta conducted batch sorption experiments to investigate the removal of metal ions using agricultural waste. They varied the temperature of the solution within the range of 298K to 343K (298, 308, 318, 328, 343K). The results indicated a notable increase in metal adsorption as the temperature rose, demonstrating a clear correlation between temperature and enhanced metal removal efficiency [22].

C. *Effect of pH of the Solution*

According to the published research, pH of the solution affected the proportion of metal ions adsorption. Vinayakamoorththy et al (2019) carried out batch sorption experiments for the removal of total iron from the landfill leachate using recycled building wastes by varying initial pH. The highest observed total iron adsorption occurred at a pH level of 8 [24]. However, when investigating the influence of initial pH on heavy metal adsorption using agricultural waste, Desta found that adsorption significantly decreased when the initial pH of the solution exceeded 6.5 [22]. Similarly, Gebretsadik et al. (2020) explored the relationship between initial pH and heavy metal adsorption by low-cost adsorbents. Their batch experiments, where they varied the initial pH of the solution, revealed that the adsorption percentage increased in the order of Cr > Pb > Cd as pH levels increased [25]. Furthermore, Panda et al. (2017) examined the impact of pH on the removal of Cr using industrial waste. They varied the pH of the solution to understand its effect on the adsorption process. Their findings indicated a rapid decrease in adsorption percentage once the pH of the solution reached 2. This decline was attributed to the weakening of the electrostatic force of attraction between oppositely charged adsorbate and adsorbent. The reduction in this electrostatic force resulted in a decreased adsorption capacity [26].

D. *Effect of Initial Ion Concentration*

Many researchers have demonstrated that the adsorption efficiency is influenced by the initial ion concentration of the solution. For instance, Gebretsadik et al. (2020) noted that the removal efficiencies of Cr, Cd, and Pb rapidly increased with higher initial concentrations of these heavy metals. The authors attributed this phenomenon to the greater number of collisions between the biosorbent and the metal ions as the initial metal ion concentration increased. This increased collision frequency resulted in enhanced adsorption efficiency [25]. Contrastingly, Panda et al. (2017) observed a decrease in the ability to remove Cr using industrial waste as the initial Cr ion concentration increased. They attributed this decline to a reduction in the availability of adsorption sites when the initial concentration was high. This decrease in available adsorption sites led to a lower removal efficiency [26].

E. *Effect of Adsorbent Dose*

The quantity of adsorbent dose plays a crucial role in adsorption, particularly in batch sorption experiments. As the amount of adsorbent dose increases, the removal percentage of heavy metals typically rises. For instance, Desta (2013) investigated the effect of increasing the amount of agricultural waste on the removal efficiency of Ni, Cu, Cr, and Pb, revealing that the removal efficiency of these metals improved as the quantity of agricultural waste increased [22]. Similarly, Gebretsadik et al. (2020) aimed to enhance the removal efficiencies of three heavy metals (Cr, Cd, Pb) using low-cost adsorbents. They systematically increased the adsorbent dosage from 0.1g to 4g, while keeping adsorbate concentration and pH constant.

TABLE 1: DETAILED SUMMARY OF HEAVY METAL REMOVAL USING LOW-COST ADSORBENTS

Type of the adsorbent	Adsorbent	Chemical Properties of the adsorbent	Tested Wastewater Type	Tested Heavy metals	Reported Average Removal Efficiencies	Treatment Technique/Process	References
Natural Adsorbents	Modified natural zeolite $(treated\ at\ 550℃)$	SiO_2 = 69.31%, Al_2O_3 = 13.11%, Fe_2O_3=1.31%, CaO =2.07%, MgO=1.13%, Na_2O=0.52%, K_2O=2.83%, SO_3=0.10%, H_2O=6.88%, Si/Al=4.66%	Synthetic solutions of heavy metal ions	Cu, Cd, Pb, Ni	99%, 99%, 100%, 87%	Adsorption	[3]
	Natural Zeolite		Wastewater	Co, Cu, Zn, Mn	77.96%, 66.10%, 45.96%, 19.84%	Batch sorption Experiments	[27]
	Natural red earth (NRE) and peat	NRE is composed of high Fe^{3+}, up to 6 %. NRE mainly consists of S $i0_2$ (54.15 %), AI_2O_3 (20.73 %) and $Fe_3\ 0_2$	Landfill Leachate	Pb	73% and 64%	Batch Sorption Experiments	[18]
	Human Hair	45 % Carbon, 28 % Oxygen, 15 % Nitrogen, 7 % Hydrogen and 5 % Sulphur.	Industrial Wastewater (Battery)	Zn, Pb & Fe	72.3%, 72.8% & 91.3%	Column Experiments	[15]
Industrial Wastes	Fly Ash	SiO_2= 40.34%, AI_20_3= 27.59%, Fe_20_3= 9.75% CaO =2.49%, MgO =0.42%, Na_20= 0,62%, K_20= 2,36% TiO_2 =2.60%	Industrial Wastewater	Fe, Pb, Cd, Cu, Ni	86.757%, 76.068%, 73.542%, 98.545%, 96.034%	Adsorption (Desorption test - To identify the amount of adsorbed adsorbate)	[20]
			Municipal wastewater treatment plant (SWTP) effluent	Cu, Pb	42%, 85%	Adsorption	[28]
	Thermally modified Concrete Waste	SiO_2 =33.04%, Al_2O_3=6.85%, Fe_2O_3=4.66%, CaO =45.86%, MgO =3.21%, SO_3=2.16%,K_2O=1.60%, Na_2O=0.18%, Other=2.44%	Aqueous solutions	Pb	92.96%	Batch Sorption Experiments	[29]
	Brick clay	Brick consists of clay which can remove the pb^{2+} ions.	Metal ion solution	Cu, Cd, Cr, Pb, Zn, Ni	100%, 100%, 100%, 100%, 94%, 94%	Column Experiments	[30]
	Concrete waste, flooring waste, brick and mortar waste, roofing waste		Landfill Leachate	Total Iron	99.6%, 97.8%, 97.9% and 95.3%	Batch Sorption Experiments	[24]
Agricultural Wastes	Sugarcane Bagasse	42% Cellulose, 25% hemicellulose, and 20% lignin	Textile wastewater	Fe, Zn	91%, 89%	Batch Sorption Experiments	[31]
			Untreated wastewater channel of Kaduna Refinery and Petrochemical Company (KRPC), Kaduna State Nigeria	Pb, Ni	89.31%, 96.33%	Batch Sorption Experiments	[32]
	Rice Husk	Rice Husk: 32% Cellulose, 21.3%Hemicellulose, 21.4% lignin, 1.82% Extractives, 8.11% Water	Synthetic wastewater	Fe, Pb, Cd, Cu, Ni	99.25%, 87.17% 67.91%, 98.17%, 96.95%	Adsorption Batch Experiments	[20]

			Metal ion solution	Cu, Cd, Cr, Pb, Zn, Ni	32%, 13%, 12%, 64%, 11%, 13%	Column Experiments	[30]
	Carbonized Rice Husk (CRH)		Textile wastewater	Pb, Cd, Cu, Zn	54.3%, 8.24%, 51.4% and 56.7%	Batch Experiments & Column Test	[21]
	Activated Rice Husk (ARH)		Textile wastewater	Pb, Cd, Cu, Zn	74.04%, 43.4%, 70.08% and 77.2%	Batch Experiments & Column Test	[21]
	Coconut wastes	20–30 wt% cellulose, 15–30 wt% hemicellulose, and nearly 50 wt% lignin	Common Effluent Treatment Plant (CETP)	Cu, Ni, Cd	100%, 99.9%, 99.57%	Adsorption	[33], [34]
	Activated Teff Straw (ATS) (Eragrostis tef)	38% cellulose, 27% hemicellulose, 18% lignin, and 10% extractives content	Textile effluents	Cr, Cd, Pb, Ni, and Cu	88% (Ni), 82.9% (Cd), 81.5% (Cu), 74.5% (Cr), and 68.9% (Pb)	Batch Sorption Experiments	[22], [35]
	Corn Cob	Ash Content =1.33% , Lignin =35.2%, Cellulose= 41.5%, Hemicellulose = 13.0% & Others 8.97%	Industrial Wastewater (Steel)	Zn, Pb, Fe & Mn	72.5%, 89.7%, 95.2% & 70.0%	Column Experiments11,30	[15], [36]
	Peanut skin	16.60% oil, 12.32% protein, 2.83% ash and 69.8% other components	Industrial Wastewater (Steel)	Zn, Pb & Fe	83.8%, 89.5% & 93.0%	Column Experiments	[15], [37]
	Bagasse	40–50% cellulose and 25–35% hemicellulose, lignin & wax	Industrial Wastewater (Steel)	Zn, Pb, Fe & Mn	93.7%, 65.4%, 83.1% & 98.2%	Column Experiments	[15], [38]

Note: Some researchers have investigated the adsorption capacities for heavy metals of relevant adsorbate.
Adsorption capacities of Corn Cob for Zn, Pb, Fe, Mn were identified as 0.0089mg/g, 0.0202mg/g, 0.0031mg/g respectively[15]
Adsorption capacities of Concrete waste, flooring waste, brick and mortar waste, roofing waste for total iron were identified as 0.43, 0.17,0.84, and 0.43 mg/g respectively[24]
Adsorption capacities of Sugarcane Bagasse for Pb, Ni were identified as 1.61mg/g, 2.6 mg/g respectively[32]

Their results showed that the removal efficiency for Cr, Cd, and Pb reached 100% when the adsorbent dosage exceeded 1g. This remarkable outcome was attributed to the increased surface area and the greater number of available ion-exchangeable sites associated with higher dosages of adsorbent [25]. Panda et al. (2017) also arrived at a similar conclusion when investigating the removal efficiency of Cr using industrial waste in batch sorption experiments. They achieved 100% removal efficiency at the maximum adsorbent dosage of 25g/L, again highlighting the increased surface area and ion exchangeable sites as key factors contributing to enhanced removal efficiency [26].

VI. Future Directions

The utilization of low-cost materials for wastewater treatment represents an area that demands extensive research efforts. One critical aspect in the practical application of these economically viable materials, especially in large-scale wastewater treatment systems, is the determination of their efficient operational lifespan. Therefore, it is imperative to conduct further experiments aimed at uncovering the effective longevity of these adsorbents. This knowledge will be essential for their sustainable and practical implementation in real-world wastewater treatment scenarios. Another critical concern associated with the use of low-cost materials is their proper disposal. Directly disposing of these materials into the environment after use poses potential environmental hazards. Therefore, it becomes essential to explore innovative techniques for material regeneration, recycling, or safe disposal. These efforts have the potential to significantly enhance the sustainability of wastewater treatment processes while simultaneously minimizing the environmental impact of used water treatment materials.

Furthermore, researchers have investigated methods to enhance heavy metal adsorption using low-cost adsorbents by modifying their natural versions. This opens the door to chemical, physical, or biological treatments aimed at altering the surface properties of these adsorbents. Such modifications can lead to improvements in their heavy metal adsorption efficiency, making them even more effective and versatile for wastewater treatment applications. Finally, one of the most critical pursuits in this field involves the integration of low-cost adsorbents with traditional wastewater treatment methods. Established techniques like coagulation-flocculation, precipitation, and membrane filtration play essential roles in wastewater treatment. Understanding how low-cost adsorbents can complement and enhance these conventional processes is of utmost significance. Such integration can yield synergistic effects, cost savings, and an overall improvement in treatment efficiency.

VII. Conclusion

Water scarcity is an escalating global concern, underscoring the urgent need to identify cost-effective methods for wastewater treatment. Among the most significant pollutants found in wastewater are heavy metals. This review is dedicated to elucidating the potential of utilizing natural, industrial, and agricultural waste-based adsorbents for the effective removal of heavy metals from wastewater. We have conducted a comprehensive summary of selected adsorbents, encompassing their chemical compositions, removal efficiencies for a range of heavy metals, adsorption capacities, the types of wastewater they are suited for, and the underlying treatment mechanisms. These low-cost adsorbents have been categorized into three groups: natural, agricultural, and industrial waste-based materials. The majority of the waste materials selected by researchers have consistently exhibited high removal efficiencies for multiple heavy metals. Moreover, our comprehensive review has uncovered that the enhancement of removal efficiencies hinges on the manipulation of several crucial factors, including contact time, solution temperature, pH levels, initial ion concentration, and the quantity of adsorbent mass. We briefly examined the repercussions of these variations on the adsorption of heavy metals onto the chosen low-cost adsorbents. Additionally, we delved into the techniques employed by researchers to augment adsorption capacities and have illuminated potential avenues for future research. In conclusion, while it is acknowledged that there are certain drawbacks associated with the utilization of low-cost materials in wastewater treatment, the application of these materials holds significant promise in mitigating impending water scarcity challenges.

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