

Review Article

Biomass-Derived Adsorbents for Dye and Heavy Metal Removal from Wastewater

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Wastewater has a high concentration of dyes and heavy metals, which are the two most significant contaminants. Due to their high toxicity and vulnerability, they possess a potential threat to human health as well as the ecosystem. There are many ways to eliminate these pollutants from water but adsorption has attained much interest because of its low cost, easy application, and no secondary pollutants. Biomass is considered an ecological burden and a reason for the reduction in the earth's carrying capacity. These materials may be used as cost-effective adsorbents to remove dyes and heavy metals from wastewater. This paper highlights recent advances made in dye and heavy metal adsorption in the last 10 years. The prime focus of this review paper is on the direct application of these biomasses without any chemical or physical alteration. The removal efficiencies and adsorption capabilities of different biomass-derived adsorbents for the removal of dyes and heavy metals from wastewater are summarised in this study. Additionally, the adsorption mechanisms underlying the removal of dyes and heavy metals using biomass-derived adsorbents have been discussed, with a focus on two kinetic models: pseudofirst-order and pseudosecond-order. Furthermore, the Langmuir and Freundlich isotherms were utilised to verify the experimental findings and to quantify the amount and degree of adsorption favorability. Based on what has been covered in the literature, the conclusion has been drawn. The future research needs are proposed in the area of biomass-derived adsorbent development, their modification for improved efficiencies, and application on large-scale wastewater treatment plants.

1. Introduction

Covering more than 70% of the Earth's surface, water is the major and most important source for the survival of this planet. Without a doubt, water is the most valuable resource among all natural resources, and for the proper functioning of Earth's ecosystem, it is a vital component. In the previous 20 to 30 years, water quality has severely degraded around the world. The major cause of its deterioration is anthropogenic activities. These major anthropogenic activities include but are not limited to the rise in the number of people, industrialisation, urbanisation that was unplanned, and natural resources being used excessively. Water from industries or even natural waters are being contaminated by harmful and toxic or sometimes carcinogenic contaminants which

are a major cause of ecological disequilibrium and causing public health issues [1]. The most prominent sources of these pollutants are the release of unprocessed sanitary water and hazardous industrial wastewater, industrial wastewater dumping, and agricultural runoff.

Among these pollutants, heavy metals and dyes are most commonly present in the wastewater and due to their toxicity and nonbiodegradability; these are extremely harmful and difficult to remove. Heavy metal pollution is present in wastewater from many industries such as tanneries, batteries, electroplating, paints, metal refining, fertilisers, and pesticides. [2]. Heavy metals can pose a serious threat to the environment and humans because of their persistency in the environment, nonbiodegradability, and accumulation tendency [3]. These heavy metals include Hg^{1+} , Zn^{2+} , Cr^{3+} ,

Cr^{6+} , Co^{2+} , Cu^{2+} , Ni^{2+} , and Pb^{2+} are categorized as toxic [4]. Because heavy metals do not disintegrate in the environment, their buildup in wastewater might lead to their relocation into water and food meant for human consumption in the long run [5]. The selected parameters limit for different heavy metals in wastewater discharge as per [6] are described in Table 1.

Dyes are being extensively used as a color reagent in industries like textiles, plastic, paper, rubber, food, and cosmetics. As a result, these dyes are left as a major waste in these industries. These are visible in the wastewater even when present at very trace concentrations because of their coloring properties. They are hazardous and sometimes pose extremely lethal effects for example allergenic, carcinogenic, and mutagenic on human as well as on aquatic life. Many organic dyes affect the food chain as well as human and aquatic life and also cause ecological problems [7, 8]. Malachite green, popular cotton, and silk dyeing chemical have been discovered to be extremely cytotoxic in mammalian cells and to promote liver tumor growth [9]. It is owing to their chemical structure that dyes are resistant to fading in the presence of light, water, and numerous chemicals, making them difficult to remove once released into the water system [10, 11]. This is a severe environmental problem, prompting scientists to work on new technologies that will allow harmful materials to be removed from polluted environmental sources.

Numerous methods for removing these contaminants from wastewater have been proposed with varying degrees of success, including oxidation, coagulation, chemical precipitation, ion exchange, solvent extraction, membrane separation, reverse osmosis, and adsorption. Many of these methods, however, have disadvantages, including high operating and maintenance costs, the generation of toxic sludge, and a complicated treatment procedure. Adsorption is one of the most effective removal techniques and has garnered much interest due to its simplicity and low susceptibility to hazardous pollutants such as dyes and heavy metals [12]. Adsorption is a mass transfer process in which metal ions are transported from the aqueous solution to the surface of the sorbent, where they are physically or chemically bonded [13, 14]. All adsorption processes need a solid-liquid equilibrium and mass transfer rates.

Many locally existing materials are being utilised as adsorbents for the exclusion of dyes and heavy metals from wastewater. Low-cost adsorbents like agricultural wastes, natural materials, and industrial products are found to be very effective and encouraging for the heavy metals and dyes removal from wastewater because of their low cost, selective sorption, no sludge production, metal recovery, and high efficiency. Several biomasses such as waste tea, peat moss, rice husk, coconut shells, and sawdust are being utilised as adsorbents. But these studies have not yet been summarised, primarily focusing on the direct application of these adsorbents without any chemical or physical alteration. The ability to utilise such materials as adsorbents without undergoing extensive and costly pretreatments makes them an appealing alternative to traditional adsorbents. They also have the benefit of being immediately available and not requiring regener-

ation; therefore, this review focuses on these adsorbents and their efficiency as well as isotherm and kinetic model studies for their ability to effectively eliminate dyes and heavy metals from the wastewater.

2. Adsorption of Dyes and Heavy Metals by Biomass-Derived Adsorbents

Biomass-derived materials are plentiful, inexpensive, and have little or no economic worth. Despite all these things, they are present in larger quantities and possess many problems for handling and disposal [15]. When compared to other dye removal techniques, dye effluents treated by adsorption produced better quality treated water. Groundwater, lakes, wetlands, and rivers are all important sources of freshwater for human existence and economic well-being yet they are often contaminated by chemicals released by industry. A long-standing human obsession with freshwater has led us to ignore the equally important advantages of water that leftovers in water courses support healthy freshwater ecosystems. As a result of diverse industries, heavy metals are released into freshwaters where they are easily absorbed by fish and marine creatures. Small quantities of heavy metals can be hazardous because they undergo bioconcentration in the human body. For example, the hexavalent Cr^{6+} ion is the most bioavailable and hence the most hazardous type of chromium.

2.1. Adsorption of Dyes. Rice husk is low-cost agricultural waste biomass that is readily available. Rice husk is made up of silica, cellulose, hemicellulose, and lignin, among other things. Abbas [16] studied the capacity of rice husk on the adsorption of 4 different kinds of dyes (i.e., methylene blue, brilliant green, Congo red, and crystal violet) from wastewater. The batch experiments were conducted based on initial concentration, absorbance material, packing height, pH, feed flow rate, treatment time, and feed temperature. The results indicated that brilliant green, crystal violet, Congo red, and methylene blue dyes had the highest removal efficacy at 95.81, 96.62, 93.44, and 96.35 percent, respectively. Efficiencies declined as initial concentration and flow rate increased but improved when bed height and feeding temperature increased. The removal efficiencies of brilliant green, methylene blue, and crystal violet dyes increased as the pH of the solution rose, while the removal efficiencies of Congo red dye dropped as the pH of the solution increased [16].

In a batch adsorption process, rice husk was utilised to remove Malachite green dye from the aqueous solution [17]. Adsorption experiments were conducted to determine the effect of solution pH, contact time, temperature, and initial dye concentration on adsorption. The pH of the medium was shown to have a significant effect on adsorption. The equilibrium adsorption findings coincide well with those predicted by the Freundlich isotherm model. Adsorption kinetics followed a pseudosecond-order model, with the rate constant rising with increasing wastewater concentration, implying that adsorption is endothermic. Additionally, rice husk was utilised to remove the dye methylene blue (MB) from wastewater. Batch studies were

TABLE 1: Heavy metal limits in wastewater as per ZDHC wastewater guidelines [6].

Sr. #	Heavy metal	Foundational (mg/L)	Progressive (mg/L)	Aspirational (mg/L)
1	Cadmium	0.1	0.05	0.01
2	Chromium (trivalent and hexavalent)	0.2	0.1	0.05
3	Copper	1.0	0.5	0.25
4	Lead	0.1	0.05	0.01
5	Mercury	0.01	0.005	0.001
6	Cobalt	1.0	0.5	0.25
7	Nickel	0.2	0.1	0.05

conducted to determine the effect of various factors. At neutral pH, MB may be efficiently eliminated. Methylene blue adsorption on rice husk was shown to increase when the temperature was increased. The Langmuir and Freundlich models were fitted to the adsorption data, and it was found that the Freundlich model matched best with the data [18]. Another research conducted by Sivakumar and coworkers on the removal of direct red 23 dye via rice husk. They eliminated direct red 23 dye from the solution using both treated and untreated rice husk. To determine the effect of dye solution concentration and adsorbent quantity on the percentage of direct red 23 removals, solutions of varying dye concentrations were produced and a known amount of adsorbents were added [19].

The adsorption characteristics of the dyes eosin Y and red X from a water solution onto the rice husk were investigated [20]. Numerous batch tests were conducted in order to determine the impact of the adsorbent dosage, contact time, initial concentration, and pH on the output. On rice husk, the adsorption kinetics of two dyes were shown to be compatible with a pseudosecond-order kinetic model. The equilibrium values for eosin Y and red X are well-matched by the Freundlich and Langmuir adsorption isotherms, respectively. The removal percentage of dyes was about 93.44% for red X ($q_e = 32.44 \text{ mg g}^{-1}$) and 90% for eosin Y ($q_e = 31.72 \text{ mg g}^{-1}$). In another study, Saroj and coworkers used maize cob, rice husk, and citrus peel-based adsorbents to remove direct blue 199 from an aqueous solution. At a constant temperature of 28°C , adsorption equilibrium studies were performed by changing the adsorbent dose. The dye's adsorption varied depending on the adsorbent. Langmuir isotherms were used to connect equilibrium adsorption data for all three adsorbents. Kinetic studies showed that 80–90 percent elimination took around 2 hours. The pseudosecond-order rate equation could properly correlate kinetic data for all of the materials investigated [21].

Patil et al. [22] studied the removal of acid yellow 17 on rice husk. Various study parameters were evaluated, and with 0.7 g of acid yellow 17 in 20 mg L^{-1} concentrated solutions, the highest color adsorption was 94.34%. The removal was shown to be strongly pH-dependent, with a maximum at 2.0 pH. Adsorption isotherms such as the Langmuir and Freundlich isotherms were studied for these adsorption studies. In the adsorption study, the Freundlich isotherm was fitted well with data. The adsorption kinetics of the first- and second-order kinetics were investigated. A

second-order reaction provided an excellent match to the adsorption data.

Seed husk of Bengal gram for the removal of Congo red dye via adsorption from an aqueous solution was studied [23]. The impact of contact time, initial concentration, desorption, and pH was determined. At lower pH levels, maximum adsorption occurred, and the dye achieved equilibrium after one hour at a concentration of 25 mg L^{-1} . With increased dye concentration, the adsorption percentage dropped to 74% from 89%, while a lower pH resulted in 92% removal efficiency. To assess the equilibrium data, Freundlich and Langmuir isotherms were employed. The greatest adsorption capacity, 41.66 mg g^{-1} , was determined using the Langmuir isotherms. Congo red adsorption was most effective when using a pseudosecond-order kinetics model.

The groundnut shell and sorghum husk were employed as adsorbents for methylene blue (MB) dye adsorption. The effect of several experimental variables on the amount of adsorption was investigated, including contact time and initial dye concentration. The results indicated that raising the dye concentration improved the proportion of MB dye removed. The Langmuir and Freundlich models were used to depict the equilibrium data. With MB dye, the maximum adsorption capacity was determined to be 7.05 mg g^{-1} for groundnut shells and 15.38 mg g^{-1} for sorghum husk, respectively. To model the adsorption data, pseudofirst and pseudosecond-order kinetic models were employed. The pseudosecond-order kinetic model was found to be the most accurate for all adsorption processes [24].

Adsorption of tartrazine yellow dye using groundnut shell was evaluated. To determine the quantity of dye adsorbed, many batch tests were conducted [25]. It was found that the adsorption efficiency is enhanced when the dosage, contact time, and operating temperature are increased. Calculated adsorption capacity increased from 0.21 mg g^{-1} to 1.21 mg g^{-1} when the dye concentration increased from 10 to 50 mg g^{-1} . Additionally, when the pH increased from 2.0 to 10, the dye concentration decreased from 0.22 mg g^{-1} to 0.20 mg g^{-1} . To assess biosorption effectiveness, Freundlich and Langmuir models were employed. Both isotherms had coefficients of determination (R^2) of 0.9988 and 0.9982, respectively. Pseudofirst-order and pseudosecond-order kinetics were also used to evaluate the experimental results. Additional studies were carried out to determine the adsorption of Congo red dye from an aqueous

solution on the surfaces of sugarcane bagasse (SB) and bambara groundnut shells (BGS). The researchers looked at the effects of pH, dose, initial concentration, and contact time on the results. The findings indicated a high efficiency of 75% and 93% with 4.5 g of BGS and SB, respectively. Additionally, when the dye loading concentration increased, the percent elimination increased, while it decreased as the pH of the solution moved up from 4 to 10 [26].

Wheat bran, an inexpensive and environmentally acceptable biosorbent, has been effectively used to remove textile dyes from water solutions. Remazol red F3B (Reactive red 180) as a model textile dye was used [27]. They investigated the impact of contact time, initial concentration, pH, temperature, and adsorbent dosage on the removal process. The optimal conditions were determined to be a contact time of 4 hours, an initial dye concentration of 200 mg L^{-1} , a pH of 2.0, an adsorbent dosage of 0.25 g, and a temperature of 20°C . The adsorption capacity of this dye was determined to be 39.42 mg g^{-1} . The results indicated that adsorption was highest at an acidic pH. By applying these optimum conditions, five other dyes were investigated. The experimental data were also evaluated for Freundlich and Langmuir models, and the results indicated that the Langmuir equation fit best for the adsorption of these dyes [28].

The adsorption of coomassie brilliant blue (CBB) on wheat bran in an aqueous solution was investigated. The adsorption behavior of coomassie brilliant blue on wheat bran by varying the pH, dosage, and contact time were studied. Up to 95.70 percent of the dye was removed from the solution onto the wheat bran under optimal conditions. The Freundlich and Langmuir adsorption isotherms were used to analyse the findings. The Freundlich model has shown to be pretty valid and to promote multilayer adsorption. The maximal capacity of adsorption, q_m , was determined to be 6.41 mg g^{-1} . Unprocessed wheat bran is an economical and efficient adsorbent for removing colors from textile industry effluent [27].

A study conducted by Alzaydien [29] discusses the use of wheat bran (WB) to remove methyl orange (MO) from polluted water. The elimination of MO from aqueous solution onto WB was studied using variables such as temperature, adsorbent dosage, pH, and contact time. The quantity of dye removed decreased when the adsorbent dosage, temperature, and contact time were increased. pH 4.0 was found to be the optimum for dye adsorption. The data on the adsorption of MO through WB was also used to generate pseudofirst-order and pseudosecond-order models. The findings suggest that using WB as a cheap adsorbent, it is possible to efficiently adsorb MO from aqueous solutions [29].

Sawdust is one of the most interesting components of agricultural waste; it is used to remove contaminants like dyes and heavy metals from contaminated water. Sawdust is readily accessible since it is waste from sawmills and is sold at a low cost. Furthermore, because sawdust is biodegradable, its disposal as trash should not damage the environment or any of its constituents. The structure of sawdust, as well as its constituents, makes it a research subject for its adsorption process. Akhouairi and colleagues

studied the adsorption of eriochrome black T dye on sawdust. The impact of different operational factors on the adsorption process was studied. Adsorption equilibrium was found to be in accord with the pseudosecond-order equation and the Langmuir model. Thus, at pH 4, the highest amount of EBT dye adsorbed was found to be $40.96 \text{ mg EBT per gram of sawdust}$, which equates to an 80 percent dye removal rate. Furthermore, the effect of several factors on the adsorption of dye, for example, dosage of adsorbent, aqueous phase pH, and dye concentration were investigated. The amount of sawdust adsorb was observed to increase when the aqueous phase pH was decreased or increased when the amount of sawdust was increased [30].

The possibility of removing Congo red from the effluent using unprocessed sawdust was examined using batch study [31]. The adsorption experiments utilised a variety of adsorbent particle sizes (90 m, 144 m, and 355 m), pH values ranging from 5.0 to 11.0, and adsorbent amounts ranging from 2.0 to 8.0 g. Additionally, depending on the application, the flow rate ranged between 0.3 and 0.7 mL min^{-1} . Sawdust that had not been treated was saturated at a lower volume. The following parameters were tested to effectively remove Congo red dye: a constant initial concentration (10 mg L^{-1} dye solution), a volume of 200.0 mL, a flow velocity of 0.3 milliliters per minute, and a particle size of 90 m [31]. The adsorption capability of methylene blue dye from polluted water was investigated using three distinct low-cost adsorbents (banana fiber, sawdust, and coconut fiber). Additional trials were conducted with an initial dosage of 250 mg L^{-1} . Temperature, pH, adsorbent dosage, and contact time were all evaluated, and it was determined that a temperature of 40°C , a pH of 7, and a contact time of 120 minutes were optimal. According to the findings, coconut fiber has a higher capacity for dye binding than the other adsorbents and may show to be an effective adsorbent for the extensive removal of compound dyes from effluents [32].

Hebeish et al. [33] studied sawdust for adsorption of direct red 23 from wastewater solution. Removal experiments were conducted to determine the removal capacity of direct red 23 on sawdust using a variety of agitation times, adsorbate and adsorbent concentrations, and the effect of each on the removal capacity of direct red 23 on sawdust. Freundlich and Langmuir models were utilised in the adsorption studies. In another research, Khattri and Singh also investigated the use of sawdust to eliminate crystal violet dye from wastewater. The feasibility of removing crystal violet using sagaun sawdust was determined by varying agitation time, adsorbent dosage, dye concentration, temperature, and pH. Adsorption effectiveness was shown to be pH-dependent. A greater proportion of dye was removed by decreasing the initial dye concentration and increasing the quantity of adsorbent. A kinetic study showed the dye's gradual adsorption on sawdust [34].

Suganya et al. [35] used sawdust to adsorb methylene blue dye from contaminated solution. Adsorption experimental parameters such as contact time, initial dye concentration, solution pH, and adsorbent dose were optimised via trial and error to achieve the maximum removal of MB dye from wastewater. To forecast system behavior, experimental

data were utilised to generate various theoretical models. The optimum conditions for maximal MB dye removal from contaminated solution were found using a 25 mg L^{-1} initial concentration of MB dye: the adsorbent dose of 3 g L^{-1} , solution pH of 7.0, contact time of 90 min, and temperature of 30°C . The pseudosecond-order and Freundlich models match the experimental data well.

To get a better understanding of the adsorption process and the potential of coir pith as biomass for pollution control due to textile dyes, in another study, Khan et al. [36] used coir pith as an adsorbent for the removal of acid yellow 99. According to the findings, 1 g of coir pith could adsorb 442.13 mg of acid yellow 99. The removal process was found to be highly pH-dependent, with 2.0 being the optimal value. The Langmuir–Freundlich dual isotherm model is used to describe the process. The potential of removing Malachite green utilising coir pith as an adsorbent derived from coconut husk was explored [37]. Contact time, agitation speed, pH, and particle size are factors in batch adsorption experiments. To fit the equilibrium data, Freundlich and Langmuir isotherms are employed. The data matched the Freundlich model well.

Hamzeh and coworkers examined the removal of acid orange 7 and remazol black 5 by changing the pH, initial dye concentration, dosage, and contact time. Both dyes exhibited their peak absorption capacity at a pH of 2.5 and a contact time of 120 minutes. The experimental findings were interpreted using a mix of Langmuir and Freundlich models. For both dyes, the isotherms are found to be linear across the full concentration range. The Langmuir model was shown to be the best match for the experimental data, with the greatest values of linear correlation coefficients for AO7 (0.9926) and RB5 (0.9882). The absorption kinetics were studied using pseudofirst- and second-order equations. A pseudosecond-order equation may predict both dyes' absorptions [38].

Pine cone as adsorbent for the adsorption of acid black 26 (AB26), acid green 25 (AG25), and acid blue 7 (AB7) in water solution was studied [39]. The impact of process variables on dye removal was investigated. These included the amount of adsorbent used, the dye concentration, the amount of inorganic anion (salt), pH, and the temperature. The kinetics data were described using the pseudofirst- and pseudosecond-order. Langmuir and Freundlich models were used to investigate equilibrium isotherms. They discovered that the isotherm data from AB26 and AG25 were consistent with Langmuir's model, while the isotherm data from AB7 were consistent with Freundlich's model [39]. Table 2 depicts the removal efficiencies of various biomass-derived adsorbents for the elimination of dyes from wastewater while Table 3 describes the adsorption capacities of several biomass-derived adsorbents for the adsorption of dyes from wastewater.

2.2. Adsorption of Heavy Metals. Coffee husk was examined for its capability to adsorb Cr^{6+} from contaminated water in an experiment conducted [41]. Researchers at the University of Texas at Austin have studied how well this adsorbent can remove Cr^{6+} ions from industrial effluent. It was then

applied to actual wastewater. Amount of adsorption as a function of pH, contact time, dosage, and initial concentration of adsorbed material was investigated. Ions of Cr^{6+} can be adsorb well utilising coffee husk within 60 min. The adsorption of Cr^{6+} ions by this adsorbent at pH 2 was maximum. The optimum conditions were 80 mg L^{-1} , 60 min, 2 g L^{-1} , 200 rpm, and 3 g L^{-1} , for the initial concentration, time contact, pH, stirring speed, and adsorbent dosage, correspondingly. A study was conducted [42] to examine the use of discarded tea and coffee grounds as low-cost adsorbents for Cr^{6+} , contact time was 180 minutes, the adsorbent dosage was 2 g, the pH was 2.0, the temperature was 30–50 degrees, and the speed of the stirring was 30 rpm (250 rpm). A strong correlation value was observed between the Freundlich isotherm and Langmuir model. There was a strong consensus between the pseudosecond-order model values for the adsorption of Cr^{6+} . Data from the experiments showed an absorptive capacity of 87.72 mg g^{-1} of coffee ground and 94.34 mg g^{-1} of mixed waste tea [42].

In addition, rice husk is a biobased adsorbent substance that may be used to eliminate pollutants from the water. It was found that rice husk, a porous carbon material, may be utilised to remove lead (Pb) and arsenic (As) from water solutions. The removal efficiency under various conditions of contact time (3–90 min), pH (3–9), and initially adsorbed concentration ($10\text{--}100 \mu\text{g L}^{-1}$), and adsorbent amount ($0.5\text{--}6 \text{ g L}^{-1}$) by varying the parameters in the adsorption reactions was investigated. Using analysis of variance, the removal efficiency was eventually determined. Optimum conditions enhanced the adsorption efficiency of As and Pb in water solutions (up to 85%, 97%, respectively) [43].

The possibility of utilising Polish peat from five distinct health sources as a heavy metal adsorbent in industrial effluent from the steel electropolishing process was studied [44]. Testing was done on the materials utilising both laboratory and industrial wastewater. Peat was used to treating model laboratory and industrial effluent with high initial metal concentrations such as Fe, Cr, Ni, and Cu. The removal rate for chromium and iron at an initial concentration of 1000 mg dm^{-3} was 99 percent, whereas nickel and copper were removed at a rate of 66%.

The capacity of several agricultural waste materials, such as almond shells (AS), walnut shells (WS), peanut shells (PS), and coconut shells (CS) to eliminate Cr^{6+} from water at room temperature and acidic pH utilising batch mode was studied [45]. While the adsorption of Cr^{6+} was adequately characterised by Langmuir model, the walnut shell provided higher adsorption yield and maximal monolayer capacity, which was found to be 37.5 mg g^{-1} . Removal of Cr^{6+} follows a pseudosecond-order according to the kinetics model. As well as this, analysis of the materials using FTIR and X-ray diffraction revealed that the adsorbent materials did not experience any change following adsorption. As a result, the type of adsorption was confirmed as physical.

Ogata et al. [46] conducted an experiment in which raw wheat bran (WB) was examined. The study also examined the adsorption of Pb^{2+} and Cd^{2+} ions on wheat bran. Equilibrium was achieved in 9 hours for the heavy metal ions,

TABLE 2: Reported removal efficiencies (%) of various biomass-derived adsorbents for the removal of different dyes.

Material	Dyes	Efficiency (%)	Reference
Rice husk	Congo red	93.44	[16]
	Methylene blue	95.81	[16]
	Crystal violet	96.35	[16]
	Brilliant green	96.62	[16]
	Direct red 23	67.5	[19]
	Eosin Y	90.0	[20]
	Red X	93.44	[20]
	Acid yellow 17	94.34	[22]
Gram seed husk	Congo red	92.00	[23]
Coconut fiber	Methylene blue	96.0	[32]
Sawdust	Methylene blue	89.0	[32]
	Eriochrome black T	80.0	[30]
	Congo red	91.33	[40]
	Direct red 23	93.0	[33]
	Crystal violet	89.46	[34]
	Methylene blue	99.15	[35]
Banana fiber	Methylene blue	85.0	[32]
Groundnut shell	Tartrazine yellow	85.2	[25]
	Congo red	75.0	[26]
Canola stalks	Acid orange 7	>90.0	[38]
	Remazol black 5	>90.0	[38]
Sugarcane bagasse	Congo red	93.0	[26]
Wheat bran	Coomassie brilliant blue	95.70	[27]

TABLE 3: Reported adsorption capacities (mg g^{-1}) of various biomass-derived adsorbents for the removal of different dyes.

Material	Dyes	q_e (mg g^{-1})	Reference
Wheat bran	Remazol red F3B	39.42	[28]
	Reactive brilliant orange 3R	34.03	[28]
	Remazol black B	38.44	[28]
	Sirius red F3B	36.03	[28]
	Telon red BN	39.15	[28]
	Telon yellow 4R	37.76	[28]
	Methyl orange	19.85	[29]
	Methylene blue	1400	[18]
	Direct blue 199	8.6	[21]
Citrus peel	Direct blue 199	12.6	[21]
Corn cob (powder)	Direct blue 199	12.7	[21]
Coir pith	Malachite green	41.46	[37]
	Acid yellow 99	442.13	[36]
Groundnut shell	Methylene blue	7.052	[24]
Sorghum husk	Methylene blue	15.40	[24]
Pine cone	Acid black 7	37.4	[39]
	Acid green 25	43.3	[39]
	Acid blue 26	62.9	[39]

TABLE 4: Reported removal efficiencies (%) of various biomass-derived adsorbents for the removal of different heavy metals.

Material	Heavy metals	Efficiency (%)	Reference
Coffee husk	Cr ⁶⁺	97.4	[41]
Rice husk	Pb ²⁺	97	[43]
	As ⁵⁺	85	[43]
Polish peat	Fe ³⁺	99	[44]
	Cr ⁶⁺	99	[44]
	Ni ²⁺	66	[44]
	Cu ²⁺	66	[44]
Walnut shell	Cr ⁶⁺	>80	[45]
Coconut shell	Cr ⁶⁺	>59	[45]
Almond shell	Cr ⁶⁺	>35	[45]
Groundnut shell	Pb ²⁺	68.2	[49]
	Cu ²⁺	77.8	[49]
	Cr ⁶⁺	87.6	[50]
Peanut shell	Cr ⁶⁺	>52	[45]
	Cr ⁶⁺	88	[48]
	Pb ²⁺	72	[52]
	Ni ²⁺	25.4	[56]
	Cu ²⁺	82	[58]
	Cr ³⁺	89	[58]
Wheat bran	Cr ⁶⁺	51	[54]
Wheat straw	Pb ²⁺	>80	[55]
	Cr ⁶⁺	>80	[55]
	Cd ²⁺	>80	[55]
Coir pith	Ni ²⁺	82	[57]
	Cu ²⁺	82	[57]
	Zn ²⁺	88	[57]

and the experimental data were fitted to a pseudosecond-order model. Correlation coefficients greater than 0.975 and 0.884 were found between the quantity of adsorbed ions and the amount of pectin or carboxy groups, respectively. Raw wheat bran (R-WB) was utilised as an adsorbent in an experiment [47]. It was determined that R-WB has certain characteristics. Pb²⁺ and Cd²⁺ ions were also tested for adsorption onto R-WB. A pseudosecond-order kinetic model was used to explain the adsorption of cadmium and lead ions on R-WB. Increasing the temperature resulted in a greater quantity of adsorption. The correlation value of the Langmuir equation is 0.996 for Pb²⁺ ions and 0.999 for Cd²⁺, whereas the Freundlich equation has a correlation coefficient of 0.993 for Pb²⁺ and 0.994 for Cd²⁺.

The biosorption of Cr⁶⁺ ions from water solution using a peanut shell (PNS) biosorbent in a batch method was investigated [48]. These factors included the initial concentrations (20-60 mg L⁻¹), pH (2 to 7), and contact time (6 hours) as well as adsorbent dose (0.2-1.0 g) and temperature (293-313 K) of the Cr ion solution. The equilibrium of adsorption was attained after 360 minutes of exposure. According to the

assessment of the kinetic models, the pseudosecond-order equation better characterized adsorption dynamics. At pH 2.0 and 3.0, the maximum removal was obtained. Compared to the Freundlich adsorption isotherm, the adsorption equilibrium values fit the Langmuir isotherm well. Using monolayer adsorption at 313 K, the removal capacity was determined to be 4.32 mg g⁻¹.

The design flexibility, low cost, and efficiency of the biosorption process have drawn the interest of numerous researchers. To test the efficacy of groundnut shells as biosorbents for the removal of Pb²⁺ and Cu²⁺ from wastewater, Kiran et al. [49] experimented. At standard temperature, a study was led to determine the impact of pH, contact time, and dose on the same sieve size groundnut shell. While both Langmuir and Freundlich isotherms were used to calculate the biosorption parameters, it was observed that the experimental data was better suited to the Langmuir model than to the Freundlich isotherm model. The results revealed that the maximum removal efficiency of Cu²⁺ and Pb²⁺ was 77.8% and 68.2%, respectively.

Many areas across the world are affected by chromium contamination of high levels in the water, sometimes from natural sources and sometimes from manmade causes. Adsorption utilising natural materials is one of the successful methods for eliminating heavy metal ions from a variety of wastewater sources, including groundwater and surface water. Groundnut shell was used as an unconventional adsorbent in batch experiments [50] to remove Cr⁶⁺ from aqueous solutions. Groundnut shells were found to adsorb Cr⁶⁺ depending on contact time, pH, initial concentration, and adsorbent dose. It was noted that the best situations for adsorption of Cr⁶⁺ were a 120-minute contact time, an adsorbent dosage of 2 g L⁻¹, an initial metal ion concentration of 25 mg L⁻¹, and a temperature of 41.5°C. Experimental data were also analysed by isotherm models and Langmuir found fitting well with data.

It was revealed by Bayuo et al. [51] that groundnut shells were utilised as an alternative and inexpensive adsorbent for the elimination of Cr⁶⁺ ions from water solution without any chemical or physical modification. Various solutions of Cr⁶⁺ were treated with fixed dosages of groundnut shell powder for 90 minutes to achieve equilibrium. The diphenyl carbazide indicator method was used to determine the Cr⁶⁺ concentration in the sample solutions using a UV-Visible spectrophotometer. It was observed that the groundnut shell has a substantial volume for adsorption of Cr⁶⁺ from aqueous solutions, according to the equilibrium isotherm experiments. According to the FT-IR findings, the groundnut shell may contain functional groups. These functional groups, such as amines, alcohols, and carboxylic acids, impact the biosorption of Cr⁶⁺ and are likely the process of adsorption [51].

According to a research conducted [52], natural adsorbents, for example, peanut shells and *Moringa oleifera* seeds may be used to remove heavy metals (lead: Pb) from textile effluent. According to the results of a batch experiment, the highest removal of lead was 86.0 percent for *M. oleifera*, 78.0 percent for *P. juliflora* seeds, and 72.0 for peanut shells when using different amounts of adsorbent and contact time.

TABLE 5: Reported parameter values for pseudofirst- and pseudosecond-order kinetic models for dye adsorption on various biomass-derived adsorbents.

Material	Dyes	Pseudofirst-order			Pseudosecond-order			Reference
		K_1 (L/min)	q_e (mg/g)	R^2	K_2 (g/mg/h)	q_e (mg/g)	R^2	
Rice husk	Eosin Y	0.034	14.06	0.921	0.00537	32.25	0.999	[20]
	Red X	0.027	5.128	0.863	0.0155	33.33	0.999	[20]
	Malachite green	—	—	—	0.0329	21.55	0.999	[17]
	Acid yellow 17	0.0648	—	0.806	0.026	—	0.996	[22]
Gram seed husk	Congo red	0.012897	4.0622	0.986	0.0658	3.8625	0.998	[23]
Coir pith	Acid yellow 99	0.008	1.023	0.768	0.042	4.182	0.999	[36]
Groundnut shell	Tartrazine yellow	8.026	0.234	0.9072	-8.09	0.208	1	[25]
	Methylene blue	0.0042	0.0783	0.3897	0.7790	2.615	0.9999	[24]
Sorghum husk	Methylene blue	0.0048	0.1093	0.2858	0.6583	2.3980	0.9996	[24]
Canola stalks	Acid orange 7	0.2211	2.41	0.8828	0.735	4.82	0.9998	[38]
	Remazol black 5	0.0459	4.50	0.9579	0.178	6.11	0.9996	[38]
Pine cone	Acid black 26	0.23	7.89	0.49	0.05	23.70	1	[39]
	Acid green 25	1.03	9.33	0.94	0.17	11.27	1	[39]
	Acid blue 7	0.90	9.91	0.95	0.13	11.55	1	[39]
Sawdust	Eriochrome black T	0.0354	2.95	0.9985	0.0325	8.89	0.9998	[30]
	Methylene blue	0.0175	17.54	0.9441	0.00067	14.74	0.9457	[35]
Wheat bran	Methyl orange	0.0134	—	0.97	0.00293	15.17	0.98	[29]
	Coomassie brilliant blue	0.002073	—	0.469	0.2989	—	0.8396	[27]

Peanut shell, *M. oleifera*, and *P. juliflora* were shown to have maximal adsorption capacities of 5.6 mg g^{-1} , 1.7 mg g^{-1} , and 1.4 mg g^{-1} of Pb, respectively. It was observed that the pseudosecond-order kinetic model was more accurate for peanut shell ($R^2 = 0.978$), *M. oleifera* ($R^2 = 0.998$), and *P. juliflora* ($R^2 = 0.995$) when related to the pseudofirst-order kinetic model.

Lead and other potentially hazardous trace elements, when found in high concentrations in soil, water, and food, pose severe health risks to people across the world. According to Bayuo et al. [53] groundnut shells may effectively remove lead from water using the batch mode method. There are some evidences that functional groups such as hydroxyls and carboxylic acids may play a role in the biosorption process through Fourier transform infrared (FT-IR) studies. With the help of various parameters, novel adsorbents, such as wheat bran (WB), were investigated to remove Cr^{6+} . According to the study, it was noted that with the rise in contact time the adsorption increased and become optimum at 180 minutes. A portion of the highly hazardous Cr^{6+} condensed to a less lethal Cr^{3+} on the WB surface as pH rose. A solution with an initial Cr^{6+} concentration of 200 mg L^{-1} had a 51.0 percent removal rate at pH 2.0. The Freundlich adsorption model characterized the isotherms of Cr^{6+} adsorption on wheat bran. At pH 2, the adsorption capacity of Cr^{6+} was 4.53 mg [54].

Mahmood-ul-Hassan et al. [55] investigated the adsorption of cadmium (Cd), chromium (Cr), and lead (Pb) from

water solution using sugarcane bagasse and wheat straw in a batch equilibrium experiment. Pb^{2+} was removed the most by both materials, followed by Cr^{6+} and Cd^{2+} . For the adsorption process, two kinetic models were used: pseudofirst-order and pseudosecond-order. The response was consistent with the second model. The lead had the greatest Langmuir maximum adsorption capacity (q_m) ($12.8\text{--}23.3 \text{ mg g}^{-1}$ sugarcane bagasse, $14.5\text{--}22.4 \text{ mg g}^{-1}$ wheat straw), while Cd^{2+} had the lowest ($1.5\text{--}2.2 \text{ mg g}^{-1}$ sugarcane bagasse, $2.5\text{--}3.8 \text{ mg g}^{-1}$ wheat straw). For all three adsorbents, the q_m was in the sequence $\text{Pb} > \text{Cr} > \text{Cd}$.

To judge the Ni^{2+} removal effectiveness of peanut shells using batch adsorption experiments, a research was conducted by Yildiz [56] using an ANN (artificial neural network) model. Researchers studied the impact of sorbent dose, contact time, and pH as well as metal concentrations and temperatures. To investigate any possible detrimental effects of the sorbent, COD (chemical oxygen demand) was determined during the experiments with different temperatures, pH, and sorbent doses. At pH 2 96.21 mg dm^{-3} COD was detected, whereas at pH 7 54.72 mg dm^{-3} COD was discovered. As the dosage of the sorbent was increased, a substantial rise in the COD value was also observed. 0.05 g of sorbent produced 12.48 mg dm^{-3} of COD, whereas 1 g of sorbent produced $282.78 \text{ mg dm}^{-3}$. As a result of isotherm investigations, the Freundlich isotherm ($R^2 = 0.97$) had the greatest regression coefficient (R^2). During kinetic experiments with changing pH levels, high pseudosecond-

TABLE 6: Reported parameter values for pseudofirst- and pseudosecond-order kinetic models for heavy metal adsorption on various biomass-derived adsorbents.

Material	Heavy metals	Pseudofirst-order			Pseudosecond-order			Reference
		K_1 (L/min)	q_e (mg/g)	R^2	K_2 (g/mg/min)	q_e (mg/g)	R^2	
Coffee ground	Cr ⁶⁺	0.0064	7.19	0.8752	0.0014	87.72	0.9996	[42]
Polish peats	Fe ³⁺	—	—	—	0.7722	11.1944	0.9999	[44]
	Cr ⁶⁺	—	—	—	1.0068	3.4407	0.9999	[44]
	Ni ²⁺	—	—	—	0.4721	0.1108	0.9990	[44]
	Cu ²⁺	—	—	—	0.2378	0.2742	0.9996	[44]
Walnut shell	Cr ⁶⁺	0.02553	30.4	0.937	0.00199	33.35	0.988	[45]
Almond shell	Cr ⁶⁺	0.02826	14.7	0.914	0.00253	17.06	0.999	[45]
Coconut shell	Cr ⁶⁺	0.02331	21.1	0.822	0.01986	21.02	0.988	[45]
Peanut shell	Cr ⁶⁺	0.02338	23.9	0.809	0.00125	28.70	0.987	[45]
	Cr ⁶⁺	7×10^{-3}	3.29	0.679	3×10^{-3}	4.01	0.902	[48]
	Pb ²⁺	0.415	—	0.991	0.022	—	0.986	[52]
	Ni ²⁺	0.091	0.686	0.96	0.140	2.211	0.99	[56]
	Cu ²⁺	1.804	7.26	0.977	0.578	7.48	0.994	[58]
Wheat bran	Cr ³⁺	0.663	7.89	0.928	0.141	8.45	0.977	[58]
	Cd ²⁺	0.39	173.5	0.958	0.01	344.8	0.999	[46]
Sugarcane bagasse	Pb ²⁺	0.12	134.9	0.334	0.01	555.6	0.999	[46]
	Cd ²⁺	—	—	—	0.088	1.2416	1.00	[55]
	Cr ⁶⁺	—	—	—	0.48	2.3513	0.99	[55]
Wheat straw	Pb ²⁺	—	—	—	0.0295	4.6253	0.922	[55]
	Cd ²⁺	—	—	—	0.08239	1.8550	1.00	[55]
	Cr ⁶⁺	—	—	—	0.03934	2.8125	1.00	[55]
Mixed tea waste	Pb ²⁺	—	—	—	0.0431	4.5085	1.22	[55]
Mixed tea waste	Cr ⁶⁺	0.0078	15.78	0.8738	0.0029	94.34	0.9992	[42]
Coir pith	Ni ²⁺	0.136	0.809	0.986	0.5311	2.066	0.999	[57]

order kinetic model regression constants ($R^2 = 0.95-0.99$) were observed. In order to better describe Ni²⁺ ion sorption on peanut shells, a pseudosecond-order kinetic model was employed since the q_e values in the second-order kinetic equation were very closely linked to the experimental results in the first-order kinetic equation.

Coir pith was tested for its ability to remove metal impurities such as Cu, Ni, and Zn from water solutions [57]. The efficacy of metal removal was evaluated in batch mode under different adsorption circumstances, including pH, the concentration of metal, and contact time. Studies on the biosorbent characteristics and SEM analysis have been carried out on the material. Lagergren pseudofirst-order and second-order models were used for kinetic modeling research. Freundlich and Langmuir isotherm models were used for equilibrium studies. A good match was discovered between all isotherms, demonstrating the effectiveness of the coir pith in heavy metal absorption. Developing adsorption techniques that take advantage of their availability and low cost might make heavy metal removal from industrial effluents more sustainable.

As a function of biomass initial concentration, initial pH, and temperature, Witek-Krowiak et al. [58] examined the biosorption of Cu²⁺ and Cr³⁺ ions from water solutions by peanut shell biomass. Optimal sorption conditions for each metal were examined individually. There was an in-depth study of biosorption's kinetics and equilibrium. To correlate experimental data and establish kinetic parameters, pseudofirst-order and pseudosecond-order kinetic models were utilised. Two two-parameter models were used to assess the experimental data (Freundlich and Langmuir). Cu²⁺ and Cr³⁺ ion affinity and adsorption capacity of peanut shells were determined using equilibrium biosorption isotherms, with monolayer sorption capacities of 27.86 mg Cr³⁺ per 1 g and 25.39 mg Cu²⁺ metal, respectively. Table 4 describes the reported removal efficiencies of various biomass-derived adsorbents for the adsorption of heavy metals.

2.3. Kinetic Studies. For the potential application in water pollution control, adsorption kinetics, which is controlled by adsorbate-adsorbent relations and system conditions,

TABLE 7: Reported parameter values for Freundlich and Langmuir isotherm models for dye adsorption on various biomass-derived adsorbents.

Material	Dyes	Freundlich			Q (mg/g)	Langmuir		Reference
		K_F (L/mg)	n	R^2		K_L (L/mg)	R^2	
Wheat bran	Remazol red F3B	10.84	2.40	0.805	65.79	0.154	0.989	[28]
	Reactive brilliant orange 3R	6.59	2.21	0.877	70.4	0.04	0.989	[28]
	Remazol black B	2.15	1.49	0.899	76.3	0.017	0.982	[28]
	Sirius red F3B	19.02	10.73	0.785	27.3	5.40	0.949	[28]
	Telon red BN	18.77	1.91	0.958	166.6	0.085	0.981	[28]
	Telon yellow 4R	4.02	1.46	0.890	96.15	0.03	0.903	[28]
	Coomassie	2.5×10^{-4}	0.53	0.940	6.410	3.502	0.973	[27]
	Brilliant blue		1.35	0.987	59.52	0.088	0.945	[27]
Rice husk	Methylene blue	7.08×10^{-13}	0.205	0.705	0.266	1015.7	0.999	[18]
	Eosin Y	2.11	1.01	0.906	58.82	0.025	0.747	[20]
	Red X	17.45	3.95	0.902	52.63	0.270	0.999	[20]
	Malachite green	4.088	1.38	0.998	12.16	0.1597	0.975	[17]
	Acid yellow 17	2.57	1.85	0.996	12.98	0.2286	0.992	[22]
Gram seed husk	Congo red	0.5767	1.2048	1	41.66	0.0102	0.99	[23]
Coir pith	Malachite green	12.10	3.98	0.913	41.665	0.078	0.890	[37]
	Acid yellow 99	17.571	2.194	0.917	449.461	0.028	0.984	[36]
Groundnut shell	Tartrazine yellow	0.3495	1.031	0.9982	3.06	0.601	0.9988	[25]
	Methylene blue	0.795	0.320	0.974	7.052	0.032	0.997	[24]
Sorghum husk	Methylene blue	5.37	0.8634	0.892	15.385	0.2089	0.8879	[24]
Canola stalks	Acid Orange 7	0.979	1.6151	0.9857	25.06	0.01671	0.9972	[38]
	Remazol black 5	2.4502	1.6231	0.9858	32.79	0.0479	0.9949	[38]
Pine cone	Acid black 7	7.95	2.58	1	37.45	0.13	0.99	[39]
	Acid green 25	7.25	2.36	0.98	43.29	0.10	1	[39]
	Acid blue 26	19.47	3.31	0.98	62.89	0.23	1	[39]
Sawdust	Eriochrome black T	2.71	1.975	0.97	42.49	0.0269	0.99	[30]
	Direct red 23	9.645	2.56	0.7099	65.8	0.064	0.9946	[33]
	Crystal violet	—	—	—	4.259	1.381	0.99	[34]
	Methylene blue	14.06	3.645	0.9848	58.14	0.234	0.9322	[35]

has been examined. Because of its relevance in the evaluation and use of adsorbents, the study of adsorption kinetics continues to attract people's interest. Additionally, the adsorbent should have a high capacity for adsorption and a fast absorption rate. The majority of adsorption research has examined adsorption kinetics using pseudofirst-order and pseudosecond-order models [59]. The kinetics of adsorption is determined by the physical and chemical characteristics of the adsorbent, as well as the mass transfer mechanism [60]. The pseudofirst-order equation which is generally expressed as [61]

$$\ln(q_e - q_t) = \ln q_e - kt. \quad (1)$$

There are two quantities of interest: the equilibrium adsorption amount q_e and the adsorption quantity q_t (mg g^{-1}), respectively, and the pseudofirst-order model's adsorption rate constant k_1 . A plot of the slope and inter-

cept of the line $\ln(q_e - q_t)$ in relation to time can be used to determine experimentally the parameters of kinetics, q_e , and K_1 .

The pseudosecond-order equation is generally expressed as [62]

$$\frac{dq_t}{dt} = k_2(q_e - q_t)^2, \quad (2)$$

where q_e and q_t are the sorption capacity at equilibrium and time t (mg g^{-1}), respectively, and k_2 is the rate constant of the pseudosecond-order sorption ($\text{g mg}^{-1} \text{h}^{-1}$). The plot of t/q_t versus t describes the pseudosecond-order model, and the values of q_e and k_2 were determined from the slopes and intercepts of the plot. Several researchers have used pseudofirst-order and pseudosecond-order models to evaluate the adsorption performance of biomass-derived

TABLE 8: Reported parameter values for Freundlich and Langmuir isotherm models for heavy metal adsorption on various biomass-derived adsorbents.

Material	Heavy metals	Freundlich			Langmuir			Reference
		K_F (L/mg)	n	R^2	Q (mg/g)	K_L (L/mg)	R^2	
Coffee husk	Cr^{6+}	—	—	0.968	—	—	0.9977	[41]
Wheat bran	Cd^{2+}	1.3	0.6	0.994	0.667	10	0.999	[47]
	Pb^{2+}	1.7	0.6	0.993	1.667	20	0.996	[47]
Peanut shell	Cr^{6+}	1.25	3.58	0.9711	3.29	0.15	0.9867	[48]
	Pb^{2+}	0.386	1.144	0.969	5.617	0.074	0.999	[52]
	Cu^{2+}	3.09	2.97	0.936	25.39	0.022	0.992	[58]
	Cr^{3+}	4.12	3.23	0.904	27.86	0.036	0.992	[58]
Groundnut shell	Cr^{6+}	0.433	1.840	0.9535	37.92	0.083	0.9905	[50]
	Pb^{2+}	0.358	1.632	0.9098	42.64	0.062	0.9554	[53]
Sugarcane bagasse	Cd^{2+}	—	—	—	1.446	0.014	0.94	[55]
	Cr^{6+}	—	—	—	4.018	0.035	0.99	[55]
	Pb^{2+}	—	—	—	12.801	0.019	0.98	[55]
Wheat straw	Cd^{2+}	—	—	—	2.528	0.032	0.99	[55]
	Cr^{6+}	—	—	—	5.066	0.082	0.99	[55]
	Pb^{2+}	—	—	—	14.513	0.034	0.99	[55]
Coir pith	Ni^{2+}	1.09	2.67	0.98	4.17	0.21	0.99	[57]
	Cu^{2+}	0.69	3.07	0.98	2.06	0.33	0.99	[57]
	Zn^{2+}	1.71	2.63	0.98	5.49	0.30	0.99	[57]

adsorbents to different dyes and heavy metals. Tables 5 and 6 show reported kinetic model parameter values for dye and heavy metal adsorption on various biomass-derived adsorbents.

2.4. Adsorption Isotherms. The adsorption isotherm is a useful tool for modeling adsorption behavior. It explains the nature and mechanism of adsorption by describing how the adsorbate interacts with the adsorbent. When comparing the adsorption capacities of different adsorbents, it is critical to analyse the isotherm data. Freundlich and Langmuir's isotherms are used to analyse experimental data and to estimate the quantity and degree of adsorption favorability in adsorption investigations. Consider a monolayer or multilayer surface phase [63]. It is generally known that there are two types of adsorption isotherms: the Freundlich and the Langmuir. The Langmuir isotherm assumes monolayer adsorption onto a surface with a finite number of adsorption sites and homogeneous adsorption methods, with no adsorbate transmigration in the surface plane [64]. The Freundlich isotherm model assumes heterogeneous surface energies, with the energy component in the Langmuir equation varying as a function of the surface coverage [65]. The Langmuir isotherm is derived by assuming that there are a finite number of adsorption sites and that adsorption is reversible.

The Langmuir adsorption isotherm model is expressed as [66]

$$q_e = \frac{q_m K_L C_e}{1 + K_L C_e} \quad (3)$$

In this equation, q_e is the quantity of dye adsorbed at equilibrium time (in mg g^{-1}), C_e is the equilibrium concentration of dye in solution (in mg L^{-1}), q_m is the maximum adsorption capacity (in mg g^{-1}), and K_L is the Langmuir isotherm constant (L mg^{-1}).

The Freundlich adsorption isotherm model is expressed as [67]

$$q_e = K_F C_e^N, \quad (4)$$

where C_e is the equilibrium dye concentration in solution (mg L^{-1}), q_e is the quantity of adsorbate at equilibrium time (mg g^{-1}), K_F is the capacity of the adsorbent, and N is the intensity of adsorption constant for Freundlich's equation. The adsorption efficiency of biomass-derived adsorbents to dyes and heavy metals has been studied by several researchers using Langmuir and Freundlich models. Tables 7 and 8 show reported dye and heavy metal adsorption isotherm parameter values onto several biomass-derived adsorbents.

3. Conclusion and Future Prospective

The use of biomass-derived adsorbents for the removal of dyes and heavy metals from wastewater is discussed in this study. It is based on a significant number of relevant research papers that have been published in the last ten years. Biomass-derived adsorbents are abundantly available and are of specific significance, easy to dispose of, and easy application. The comparisons of different adsorbents are

also discussed by their removal efficiencies and adsorption capacities. The adsorption rate is an essential consideration when selecting an adsorbent since the adsorbent should have a high adsorption capacity and a rapid adsorption rate. For this purpose, the data was also collected for two main kinetic models. An adsorption isotherm is a useful tool for modeling adsorption behavior. In adsorption studies, Langmuir and Freundlich's isotherms are used to fit the experimental data, and how to determine the amount and degree of adsorption favorability was also discussed. In general, this study emphasizes the benefits of utilising adsorbents generated from biomass for the removal of dyes and heavy metals. As shown by the study of the literature, the majority of adsorption studies are carried out on a batch scale and have not been fully developed for the treatment of real industrial effluents at pilot and industrial scales. Additionally, the actual industrial effluents were contaminated with a variety of contaminants, necessitating extensive research into the selectivity of adsorbents in actual effluents. More studies are required to evaluate the adsorption of these adsorbents on real wastewater treatment plants and pilot scales as well as the assessment of challenges in the application of these biosorbents on large-scale wastewater treatments.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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