ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

Rice Husk as A Versatile Biosorbent: A Systematic Review of Wastewater Treatment Applications

Aastha. D Patel, #Dr. Milan. M Lakdawala, Falguni Patel, Sonal Chaudhary

Department of Chemistry, Shri Govind Guru University, Vinzol, Gujarat, India.

#Assistant Professor, Sheth P.T. Arts and Science College, Godhra, Gujarat, India.

DOI: https://doi.org/10.51583/IJLTEMAS.2025.140600082

Abstract -Rice husks, an abundant agricultural waste product, have emerged as a versatile and sustainable biosorbent for wastewater treatment applications. This systematic review comprehensively examined the effectiveness of rice husks and their derivatives in removing a wide range of pollutants, including heavy metals, organic compounds, inorganic anions, and emerging contaminants. Various modification strategies, such as chemical activation, thermal treatment, and nanostructuring, have enhanced the adsorption capacity and selectivity of rice husk adsorbents. This review highlights the potential of rice husks in addressing specific wastewater challenges, including BOD and COD reduction in dairy effluents, casein recovery, and nutrient removal. The adsorption process is influenced by several factors, such as pH, adsorbent dosage, contact time, and temperature, and conforms to well-established isotherm and kinetic models. Rice husk-based materials have demonstrated high removal efficiencies for heavy metals (e.g., Zn, Pb, Cu, and Ni), organic pollutants (e.g., phenols, dyes, and surfactants), and nutrients (e.g., ammonium and phosphate). Furthermore, the eco-friendly nature and cost-effectiveness of rice husks position them as sustainable alternatives to conventional adsorbents, aligning with the principles of a circular economy. However, despite significant progress has been made, further research is required to optimize modification techniques, explore new applications, and scale up these technologies for industrial use. This review underscores the promising role of rice husks in advancing sustainable wastewater treatment and resource recovery.

Keywords: Rice husk, Wastewater treatment, Adsorption, Nanostructured, Chemical modification, Organic pollutants, Inorganic pollutants

I. Introduction

After air, water is an essential natural resource for all living organisms on our planet. However, rapid industrial development has led to the discharge of large quantities of pollutants into water bodies, significantly contributing to water pollution problems.[1] Consequently, there is an urgent need for cost-effective and efficient wastewater treatment technology.[2] The growing issue of global water scarcity underscores the importance of sustainable food production, which increases the need to reuse treated wastewater for agricultural irrigation to combat hunger, poverty, and malnutrition in the future.[3]

Wastewater produced from agricultural, industrial, and domestic activities contains varying concentrations of harmful inorganic substances (such as heavy metals and excess nutrients) and biodegradable and non-biodegradable organic contaminants (including dyes and polyaromatic hydrocarbons), all of which pose severe risks to human health and the environment. Among these, potentially toxic elements (PTEs), a group of trace metals with densities greater than 4 ± 1 g cm^{-3}, are particularly concerning. This group of elements included copper (Cu), mercury (Hg), cadmium (Cd), zinc (Zn), tin (Sn), iron (Fe), lead (Pb), silver (Ag), manganese (Mn), chromium (Cr), cobalt (Co), arsenic (As), aluminum (Al), and nickel (Ni).[4]

Wastewater pollutants are broadly categorized as either organic or inorganic. Organic pollutants include pesticides, phenols, herbicides, petroleum products, dyes, oils, polychlorinated biphenyls, fats, proteins, starches, and pharmaceuticals, whereas inorganic pollutants mainly consist of chemical fertilizers, heavy metals, and excess nutrients. Both categories contribute to the deterioration of water quality and create serious environmental problems.[5,6] To minimize these risks, various treatment technologies have been developed, including membrane filtration, reverse osmosis, chemical precipitation, solvent extraction, oxidation and adsorption.[7] Among these, adsorption is particularly noteworthy because of its simplicity, ease of operation, and cost-effectiveness. With advancements in materials science, the focus has shifted toward developing low-cost, high-efficiency adsorbents derived from abundant natural resources such as agricultural waste materials.[4] Therefore, this study aims to comprehensively review the application of rice husks and their derivatives in wastewater treatment, focusing on material properties, modification techniques, and their interactions with a wide range of organic and inorganic pollutants.

Properties of Rice Husk and Its Derivatives

Rice husks are among the most abundant agricultural waste products produced globally during rice milling processes. Improper disposal of rice husks, particularly through open-air combustion, poses a significant environmental threat, leading to the emission of carbon dioxide (CO_2), methane, and persistent smoke into the atmosphere.[8] Chemically, rice husks comprise approximately 31% cellulose, 22% hemicellulose, 20.5% lignin, 20% silica, and 4% crude protein content. Their granular structure, enriched with floristic fibers, and characteristics such as water insolubility, chemical stability, and high mechanical strength make rice husks a promising candidate for adsorption-based applications. In addition, the presence of functional groups, such as carboxyl (–

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

COOH), hydroxyl (–OH), and amidogen (–NH_2) groups, enhances the interaction between rice husks and a wide range of pollutants. These functionalities contribute to its adsorption capacity and selectivity, reinforcing its potential as a low-cost, eco-friendly adsorbent for wastewater treatment.[9]

However, raw rice husks contain natural waxes and fats on their internal surfaces, which act as impurities and adversely affect their adsorption performance, both chemically and physically.[10] These hydrophobic components limit the availability of active binding sites, thereby reducing the pollutant removal efficiency of the adsorbent. Fortunately, such limitations can be mitigated through chemical or thermal pretreatment, which removes surface impurities and improves the porosity and surface reactivity of the materials. Owing to their widespread availability, low cost, and growing need for sustainable waste management, rice husks have garnered attention from commercial industries as viable alternatives to conventional adsorbents.[11] Its valorization not only helps address environmental disposal challenges but also promotes the principles of the circular economy by transforming agricultural waste into value-added materials for environmental remediation. The chemical composition of rice husk ash (RHA) as determined by X-ray fluorescence (XRF) includes 89% SiO_2, 1.20% Al_2O_3, 18.24% C, 1% CaO, 1.22% K_2O, and 1.28% Fe_2O_3.[12] Due to its high silica and metal oxide content, rice husk ash is a promising, low-cost adsorbent for wastewater treatment.

Fundamentals of Adsorption in Wastewater Treatment

Definition and Types of Adsorption Systems

Adsorption refers to the accumulation of a substance at the interface between two phases, leading to a concentration difference relative to the bulk phase of the adsorbent.[13] This phenomenon can occur across various systems, such as solid–liquid, solid–gas, liquid–gas, and liquid–liquid interfaces. In recent years, adsorption has become one of the most widely used techniques in industrial wastewater treatment because of its simplicity, efficiency, and ability to remove contaminants at low concentrations. For example, it is highly effective in removing and recovering heavy metals from wastewater.

Factors Affecting Adsorption Efficiency

The effectiveness of the adsorption process is influenced by several key parameters, including solution pH, adsorbent dosage, contact time, and temperature. Among these factors, pH plays a critical role in regulating the surface charge of the adsorbent and ionization of the adsorbate, thereby affecting the adsorption capacity. Identifying the optimal initial pH is essential for maximizing the pollutant removal efficiency. The adsorbent dosage directly affects the surface area available for adsorption and determines the equilibrium between the adsorbent capacity and adsorbate concentration. An appropriate dose ensures high removal efficiency without unnecessary material usage.[13]

Isotherm and Kinetic Models in Adsorption

Researchers often use adsorption isotherms and kinetic models to analyze and predict adsorption behavior. An adsorption isotherm illustrates the relationship between the equilibrium concentration of a solute in a solution and the amount adsorbed on the surface of a solid. Two of the most commonly applied isotherm models are as follows:

Langmuir isotherm model: assumes monolayer adsorption on a homogeneous surface with finite adsorption sites.

Freundlich isotherm model: This model describes multilayer adsorption on heterogeneous surfaces with variable adsorption energy.

These models help evaluate adsorption capacities, predict system behavior, and guide adsorbent design, and these theoretical foundations are directly applicable to biosorbents, such as rice husks, which primarily function through adsorption. Understanding these principles is essential for interpreting the performance of rice husks and their derivatives in wastewater treatment applications.[14,15]

Modification Strategies for Rice Husk Adsorbents

Building on their inherent physicochemical properties, rice husks have been extensively investigated for the removal of pollutants, including heavy metals and organic compounds. Adsorption studies were conducted in both batch and continuous operational modes. The efficacy of rice husks depends largely on whether they are used in their raw or modified forms.

This section elaborates the details about the specific modification techniques, such as chemical activation or thermal treatment, directly enhance the adsorption capacity of rice husks for different pollutants, drawing clear connections between the modification process and its impact on performance, including mechanical (e.g., grinding), physical (e.g., heat or pyrolysis), and chemical (e.g., acid/base washing, metal salt impregnation) treatments, and their combinations. These methods significantly enhance the surface area, porosity, and number of functional groups, thereby improving adsorptive efficiency. Recent developments in physicochemical and biological modifications show promise for further optimizing wastewater treatment.[16]

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

In one study, biochar derived from rice husk pyrolyzed at 900°C for 90 min achieved a high surface area (~280 m^2/g) and porosity (~0.316 cm^3/g), with a favorable microporous and mesoporous structure. These characteristics make it a strong candidate for water purification and soil remediation.[17] Further research evaluated biochars from rice husks and sawdust at 300°C and 700°C. High-temperature biochar demonstrated a higher nitrate adsorption capacity (up to 95.42 mg/g), whereas low-temperature biochar was more effective for phosphate adsorption (up to 47.18 mg/g). Adsorption kinetics revealed that nitrate removal followed chemisorption, as described by the pseudo-second-order model ($R^2 > 0.96$), whereas phosphate adsorption was governed by both pore diffusion and chemisorption. When applied to soil, nutrient-loaded biochar significantly enhanced maize growth, increasing fresh biomass by up to 803% and dry biomass by 733%, along with greater uptake of Zn, Mn, Fe, Ca, and Mg.[18]

Rice husk ash (RHA), a byproduct of husk combustion, was transformed into a solid-phase extraction (SPE) sorbent (nC-RHA@SiO_2) for preconcentrating steroidal hormones from natural water samples. XPS and HAADF-STEM analyses confirmed the presence of oxygenated functional groups responsible for the high adsorption efficiency of the adsorbent. A simplified analytical method using solid-phase extraction (SPE) followed by HPLC-MS/MS enabled the quantification of multiple classes of target compounds. Notably, this one-pot oxidation approach reduced acid usage and yielded CQD-RHA@SiO_2, a valuable carbon-based byproduct with potential applications.[19]

Additionally, biochar produced via the microwave-assisted pyrolysis of rice husks exhibited nutrient adsorption and partial recovery capabilities. The adsorption of phosphate and nitrate reached 65% and 75%, respectively. Desorption studies demonstrated 96.6% release of phosphate and 44.4% of nitrate, indicating the potential reuse of nutrient-laden biochar as a slow-release fertilizer.[20]

Applications of Rice Husk and Its Derivatives in Wastewater Treatment

Removal of Heavy Metals

Rice husks and their derivatives have been widely explored for their potential to adsorb heavy metals from aqueous environments, providing a sustainable and low-cost solution for industrial wastewater treatments. Researchers investigated the efficacy of rice husk as an adsorbent for Zn^{2+} and Pb^{2+} removal from dairy industry effluents. The optimal conditions resulted in maximum adsorption capacities of 0.3 mmol/g for Zn^{2+} and 0.003 mmol/g for Pb^{2+}, achieving removal efficiencies of 70% and 96.8%, respectively. The process followed the Langmuir isotherm model, indicating monolayer adsorption behavior.[21]

One of the studies highlights the data about the broad potential of rice husks for removing various metals, including cadmium (Cd), lead (Pb), zinc (Zn), copper (Cu), cobalt (Co), nickel (Ni), and gold (Au).[22] One of the research studies sheds light on the synthesis of the mesoporous iron-oxide/rice husk composites and their application for Pb^{2+} and Cu^{2+} adsorption. These composites showed improved removal efficiencies compared to raw or carbonized rice husk alone, suggesting a synergistic effect between the iron phases and carbonized RH.[23]

Rice husk biochar produced at increasing pyrolysis temperatures (300–700°C) exhibited a corresponding increase in surface area and lead adsorption capacity (from 14.1 to 26.7 mg/g). Notably, RH300 showed the highest exchangeable Pb, indicating a better aqueous phase removal potential, whereas RH500 and RH700 immobilized Pb in stable forms, such as Hydrocerussite and Pyromorphite, which are suitable for soil remediation.[24] Further investigation into the role of silica and mineral impurities in rice husk ash (RHA) demonstrated that when carbon is retained during pyrolysis, it prevents silica sintering and maintains microporosity (~300 m^2/g), achieving nickel removal efficiencies exceeding 99%.[25]

In the hydrothermal treatment (HTT) of sewage sludge, the addition of rice husks significantly reduced heavy metal leachability. The optimal RH-to-sludge ratio (1:1.75, d.w.) resulted in no detectable eco- or leaching toxicity. The immobilization efficiency followed the order Cu ≈ Pb ≈ Cd > Ni > Cr, which was attributed to RH's strong binding capacity of RH.[26]

A pyrolysis-based study using rice husks, wheat straw, and corncob produced biochars capable of removing Pb and Cd from industrial wastewater. RH-derived biochar showed 96.41% Pb and 94.73% Cd removal, proving its comparability with other agricultural residues.[27] A novel solid-phase biosorbent prepared from rice husks achieved an adsorption capacity of 198.2 mg/g for Pb^{2+}. At pH 4.0, the use of just 50 mg of the material resulted in nearly complete extraction, achieving a remarkably high preconcentration factor of 200, indicating that the target analyte was enriched up to 200 times its original concentration. The biosorbent maintained its performance over 10 adsorption/desorption cycles using thiourea for regeneration.[28]

Comprehensive studies have confirmed that both unmodified and modified rice husks efficiently remove a spectrum of metal ions, including rare and radioactive elements. Mechanical grinding enhances the adsorption potential, whereas thermal treatment above 350°C requires additional activation. Chemical modifications can further increase adsorption but may incur costs and environmental concerns. Alkaline treatment is a common method for producing high-quality RH-based adsorbents.[29]

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

Table I: Heavy metal removal efficiencies using rice husks.

Adsorbate	Adsorption conditions	Maximum adsorption capacity	Reference
Zn (II)	Cs: 1 g/L; Cm:10–100mg/L; pH 3.5; T: 30°C; t: 240min; agitation:150rpm	12.41 mg/g 20.08 (NRH) mg/g	[30]
Cr (VI)	Cs: 40 g/L; Cm: 50mg/L; pH 2.2; T: 30°C; t: 30min; agitation: 160rpm	99–100%	[31]
Pb (II)	Cs: 2 g/L; Cm: 50mg/L; pH 5; T: 60°C	8.60 mg/g	[32]
Cu (II)	Cs: 5 g/L; Cm: 10mg/L; T: 30°C; t: 90min; agitation: 150rpm	74%	[33]

Note: NRH: NaOH-treated rice husk; Cs: concentration of sorbent; Cm: initial concentration of heavy metal; T: adsorption temperature; t: adsorption time

Table II: Heavy metal removal efficiencies using rice husk ash.

Adsorbate	Adsorption conditions	Maximum adsorption capacity	Reference
Fe (II)	Cs: 5 g/L; Cm: 100mg/L; pH 5; T: 30°C; t: 420 min;	18.84 mg/g	[34]
Cr (VI)	Cs: 15 g/L; Cm: 50mg/L; pH 2; T: 30°C; t: 60min;	98.46 mg/g	[35]
Pb (II)	Cs: 5 g/L; Cm: 3–100mg/L; pH 5; T: 30°C; t: 60min;	99.3%	[36]

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

Ni(II), Zn(II), Mn(II),Co(II, Cu(II),Cd(II), Hg(II), Pb(II)	Cs: 3 g/L; Cm: 50–200 mg/L; pH 6 (except for Hg and Cu at pH 5.5); T: 32°C; t: 180 min; agitation: 200 rpm.	5.52 mg/g, 8.14 mg/g, 8.30 mg/g, 9.57 mg/g, 10.9 mg/g, 16.7 mg/g, 36.1 mg/g, 58.1 mg/g	[37]

Note: Cs: concentration of sorbent; Cm: initial concentration of heavy metal; T: adsorption temperature; t: adsorption time.

BOD and COD Reduction from Dairy Effluent

Rajput et al.[38] reported the effective use of rice husk as a low-cost adsorbent for treating dairy industry wastewater. Under optimized conditions—an adsorbent dose of 800 mg/L, pH 7.37–7.4, and temperature of 27 °C—the system achieved high biological oxygen demand (BOD_3) removal efficiencies of 89.2% and 73.11%, respectively, in two different experimental trials. Notably, this study found that rice husk treatment was particularly efficient when applied after preliminary filtration, leading to substantial reductions in organic pollutant load. These results underscore the suitability of rice husks for dairy effluent treatment owing to their porous structure, abundant availability, and low cost of treatment. Furthermore, this study emphasized the critical role of pH in influencing the electrostatic interactions between the rice husk surface and charged pollutants. These findings position rice husk as an effective material for large-scale dairy wastewater management, particularly in regions with abundant rice production.

Casein Adsorption and Protein Recovery from Dairy Wastewater

In a novel application, rice husks were employed for the adsorption of casein, a major milk protein, from dairy effluent, enabling pollution control and resource recovery. This method not only reduces the organic load in wastewater but also facilitates the extraction of valuable proteins that can be repurposed as high-protein animal feed. The optimal conditions for casein adsorption were as follows: 30 min contact time, 4 mg/mL adsorbent dosage, and an alkaline pH up to 9.93. Under these parameters, a significant adsorption efficiency was achieved. The dual functionality of this approach—environmental remediation and by-product recovery—aligns with the principles of the circular economy and sustainable waste management strategies.[39]

Removal of Inorganic Anions and Non-Metallic Contaminants

Fluoride contamination of drinking water is a major public health concern worldwide. Tanvir Arfin et al.[40] investigated the adsorption potential of rice husk ash (RHA) for the removal of fluoride ions from aqueous solutions. This study demonstrated that RHA, owing to its high surface area, porous structure, and the presence of reactive functional groups, is a cost-effective and efficient biosorbent for the removal of fluoride. These characteristics enable strong electrostatic interactions with negatively charged fluoride ions, supporting their application in decentralized water purification systems, particularly in rural regions affected by fluoride.

Phosphorus Recovery from Wastewater

Sharmin et al.[41] investigated calcium silicate hydrate (CSH) synthesized from rice husks for phosphorus removal from synthetic wastewater. The study found that CSH's phosphorus removal efficiency of CSH was highly affected by alkalinity. Under high-alkalinity conditions (5,000 mg/L as $CaCO_3$, pH 9), the removal efficiency decreased owing to calcite formation, which limited the free calcium ions required for phosphorus precipitation. However, at lower alkalinity levels (up to 307 mg/L as $CaCO_3$), the removal efficiency improved significantly, reaching ≥99%, which is comparable to the results in deionized water. Phosphorus recovery from spent CSH was also tested using modified soil-extraction methods. CSH exposed to deionized water released the most phosphorus under acidic and alkaline conditions, whereas CSH from highly alkaline water showed better recovery under acidic and neutral conditions. Overall, rice husk-derived CSH was effective for phosphorus removal and recovery, supporting its use in nutrient recycling and circular economy practices.

Removal of Organic Pollutants

Rice husks and their derivatives, particularly biochar and ash, have been extensively studied for their effectiveness in removing a variety of organic pollutants from wastewater, including phenols, antibiotics, pharmaceuticals, dyes, and complex organic matter from domestic, livestock, and industrial effluents.

Mankomal et al.[42] demonstrated that biochar derived from rice straw can remove up to 70% of phenol from aqueous solutions within 60 min, highlighting its utility as a cost-effective and environmentally friendly adsorbent for phenol-contaminated industrial wastewater. In another study, rice straw biochar was tested for livestock wastewater treatment. With an optimal contact

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

time of 3 h, a dosage of 4 g/L, and pH 9, batch experiments yielded up to 40% removal of COD and BOD_5. Column experiments further improved the removal efficiencies to 79% (COD) and 84% (BOD_5) for the two-step biofilter. The treated effluent met Vietnam's discharge standards for livestock wastewater, demonstrating the real-world applicability of biochar.[43] India faces a severe gap between sewage generation (~40,000 MLD) and sewage treatment capacity (~11,786 MLD). In this context, rice husk ash (RHA), an abundant agricultural by-product, was found to significantly reduce the COD, BOD, TDS, TSS, turbidity, and color of municipal wastewater. Its dual function as an adsorbent and coagulant positions RHA as a low-cost, sustainable alternative for municipal wastewater treatment.[44]

Rice husks were also tested as a filtration medium for greywater treatment in this study. The results indicated substantial improvements in both physical and chemical parameters: turbidity (−50%), TDS (−75%), acidity (−25%), and BOD (−35%). However, this study cautioned against the direct reuse of filtered greywater for irrigation due to potential health risks, suggesting the addition of coagulants for safer application.[45]

A hybrid biofilter system made from a 50:50 mix of rice husks and sawdust (60 cm column height), combined with Cyperus papyrus L., Eisenia foetida (earthworms), and a microbial consortium, showed high efficiency in greywater treatment. When operated at a hydraulic loading rate of 3 m^3/m^2/day, the system significantly reduced contaminants: COD to 40–80 mg/L, NH_4^+ to 0.12–0.6 mg/L, and pathogens to 7×10^2 MPN/100 mL, making the treated water suitable for non-food crop irrigation. The biofilter medium supported strong biological activity, with Cyperus papyrus and Eisenia foetida achieving growth rates of 50% and 53 %, respectively. It also showed no clogging or head loss, even at higher flow rates of 5 m^3/m^2/day. This cost-effective, decentralized system presents a scalable solution for rural and semi-urban areas that lack centralized wastewater infrastructure. However, further research is needed on its ability to remove emerging contaminants, such as pharmaceuticals and viruses.[46]

A novel rice hull/$MnFe_2O_4$ composite (RHM) was synthesized for the treatment of organic wastewater via combined adsorption and catalytic degradation. The composite, produced under a nitrogen atmosphere, achieved up to 73.5% COD removal within 6 min of microwave irradiation. The enhanced performance was attributed to the catalytic activity of the embedded $MnFe_2O_4$ nanoparticles, despite RHM having a lower surface area than conventional RHA.[47] Lugo-Arias et al.[48] investigated nutrient biosorption using rice husks and corn residue. Through multicriteria analysis, the review highlighted up to 99% removal of nitrates and phosphates, showcasing the dual benefits of pollution removal and potential nutrient recovery.

Rice husk ash has also been proven to be an effective, natural coagulant. Its efficiency varies with pH and concentration; at low doses, a higher pH favors coagulation, whereas at higher doses, a lower pH improves performance. Optimum kaolin coagulation was observed at 1500 mg/L RHA, 40 min of stirring, and pH 3.0.[49]

Chemically activated carbon from rice husks achieved significant COD removal from wastewater, with a maximum Langmuir adsorption capacity of 45.9 mg/g. Adsorption equilibrium was reached within 100 min and was influenced by the pH, adsorbent dosage, contact time, and temperature. Its high surface area and porosity make it suitable for industrial wastewater treatment.[50]

Biochar derived from rice husks (RBC) was evaluated as an efficient activator of peroxymonosulfate (PMS) for the degradation of organic pollutants, such as bisphenol A (BPA) and tetracycline (TC). The RBC/PMS system achieved over 90% removal of both compounds within 60 min, with sustained performance over five cycles of operation. Mechanistically, RBC's defect-rich structure of RBCs promotes radical formation through electron donation. The potential of real industrial wastewater treatment was confirmed, with 90.3% and 87.2% removal of BPA and TC, respectively.[51] Tofu production, often carried out on a domestic scale, usually lacks proper wastewater treatment, resulting in effluents rich in COD, BOD, and suspended solids that can harm water quality. A study explored the use of Vetiveria zizanioides (vetiver grass) and a novel adsorbent called zeliac, composed of zeolite, activated carbon, limestone, rice husk ash (RHA), and cement, for treating tofu wastewater. Using Response Surface Methodology (RSM) and central composite design, the study evaluated treatment durations (3, 9, and 15 days) and wastewater concentrations (20%, 40%, and 60%). Optimal treatment was achieved at 15 days and 38.41% concentration, with removal efficiencies of 76% COD, 71.78% BOD, and 75.28% TSS. These results highlight the potential of rice husk-based materials in cost-effective, integrated systems for treating wastewater from small-scale tofu production.[52]

Removal of Surfactants and Emerging Contaminants

The potential of rice husks (RH) and rice husk ash (RHA) as low-cost adsorbents for removing surfactants from wastewater has been extensively investigated. One study reported a maximum removal efficiency of 97% for anionic surfactants (sodium linear alkyl sulfonate, 10 mg/L) at pH 2 and 75% removal for nonionic surfactants (nonyl phenol ethoxylate, 20 mg/L) at pH 6–7.[53]

The adsorption efficiency is influenced by several factors, including the physicochemical properties of RH, micelle size, and critical micelle concentration (CMC). Interestingly, RHA contributed minimally to the removal process, indicating that raw RH possesses more favorable structural and functional attributes for surfactant adsorption than RHA. RH has also been explored as a biosorbent for the removal of toxic mycotoxins, such as aflatoxins B1 and M1, from milk. Under optimized conditions, nearly 100% removal of these toxins was achieved.[54] This approach offers a low-cost, environmentally friendly alternative to traditional solvent-intensive methods, reducing reliance on hazardous chemicals while ensuring milk safety.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

Removal of Synthetic Dyes

Rice husk ash (RHA) effectively adsorbs Indigo Carmine (IC) dye from aqueous solutions, reaching equilibrium within 8 hours and following pseudo-second-order kinetics, indicating chemisorption as the main mechanism. The adsorption process was endothermic, with improved efficiency at higher temperatures, and capacities ranging from 29.3 to 65.9 mg/g between 293 and 323 K. The data best fit the Freundlich and Redlich–Peterson isotherm models. A negative Gibbs free energy change ($\Delta G°$) confirmed the spontaneous nature of adsorption, whereas a positive entropy change indicated increased randomness at the solid–liquid interface.[55]

Nutrient Removal: Ammonium Removal

Magnesium-modified rice hulls (MCRH) have demonstrated high efficacy in ammonium removal from both synthetic and domestic wastewater. At an adsorbent dosage of 1.8 g/L and a treatment duration of 27 h, MCRH achieved 90.7% removal efficiency for an initial ammonium concentration of 81.3 mg/L. The adsorption process conformed to the Langmuir isotherm model, indicating monolayer adsorption, while kinetic analysis revealed that the intraparticle diffusion model best described the process, suggesting that it was the rate-limiting step. These results highlight the potential of MCRH as a promising and sustainable material for nutrient recovery and secondary wastewater treatment applications.[56]

II. Conclusion

This systematic review comprehensively examined the versatile applications of rice husks and their derivatives in wastewater treatment. This study highlights the effectiveness of rice husk-based materials in removing a wide range of pollutants, including heavy metals, organic compounds, inorganic anions, and emerging contaminants. Various modification strategies, such as chemical activation, thermal treatment, and nanostructuring, have been shown to enhance the adsorption capacity and selectivity of rice husk adsorbents. This review also emphasizes the potential of rice husks in addressing specific wastewater challenges, such as BOD and COD reduction in dairy effluents, casein recovery, and nutrient removal. Furthermore, the eco-friendly nature and cost-effectiveness of rice husks position them as sustainable alternatives to conventional adsorbents, aligning with circular economy principles. However, while significant progress has been made, further research is needed to optimize modification techniques, explore new applications, and scale up these technologies for industrial use. Overall, this review underscores the promising role of rice husks in advancing sustainable wastewater treatment and resource recovery.

References

1. Kaur, N. (2021). Different treatment techniques of dairy wastewater. Groundwater for Sustainable Development, 14, 100640. https://doi.org/10.1016/J.GSD.2021.100640
2. De La Cueva Bueno, P., Gillerman, L., Gehr, R., & Oron, G. (2017). Nanotechnology for sustainable wastewater treatment and use for agricultural production: A comparative long-term study. Water Research, 110, 66–73. https://doi.org/10.1016/j.watres.2016.11.060
3. Inyinbor, A. A., Bello, O. S., Oluyori, A. P., Inyinbor, H. E., & Fadiji, A. E. (2019). Wastewater conservation and reuse in quality vegetable cultivation: Overview, challenges and future prospects. In Food Control (Vol. 98, pp. 489–500). Elsevier Ltd. https://doi.org/10.1016/j.foodcont.2018.12.008
4. Younas, F., Mustafa, A., Farooqi, Z. U. R., Wang, X., Younas, S., Mohy-Ud-din, W., Hameed, M. A., Abrar, M. M., Maitlo, A. A., Noreen, S., & Hussain, M. M. (2021). Current and emerging adsorbent technologies for wastewater treatment: Trends, limitations, and environmental implications. In Water (Switzerland) (Vol. 13, Issue 2). MDPI AG. https://doi.org/10.3390/w13020215
5. Ali, M. H. H. (2008). Assessment of some water quality characteristics and determination of some heavy metals in Lake Manzala, Egypt. In Aquat. Biol. & Fish (Vol. 12, Issue 2). www.esfhd.eg.net
6. Alssgeer, H. M. A., Gasim, M. B., Hanafiah, M. M., Abdulhadi, E. R. A., & Azid, A. (2018). GIS-based analysis of water quality deterioration in the Nerus river, Kuala Terengganu, Malaysia. Desalination and Water Treatment, 112, 334–343. https://doi.org/10.5004/dwt.2018.22335
7. WATER ENCYCLOPEDIA DOMESTIC, MUNICIPAL, AND INDUSTRIAL WATER SUPPLY AND WASTE DISPOSAL. (n.d.).
8. Okoro, H. K., Alao, S. M., Pandey, S., Jimoh, I., Basheeru, K. A., Caliphs, Z., & Ngila, J. C. (2022). Recent potential application of rice husk as an eco-friendly adsorbent for removal of heavy metals. In Applied Water Science (Vol. 12, Issue 12). Springer Science and Business Media Deutschland GmbH. https://doi.org/10.1007/s13201-022-01778-1
9. Pathak, U., Das, P., Banerjee, P., & Datta, S. (2016). Treatment of wastewater from a dairy industry using rice husk as adsorbent: Treatment efficiency, isotherm, thermodynamics, and kinetics modelling. Journal of Thermodynamics, 2016. https://doi.org/10.1155/2016/3746316
10. Ndazi, B. S., Karlsson, S., Tesha, J. V., & Nyahumwa, C. W. (2007). Chemical and physical modifications of rice husks for use as composite panels. Composites Part A: Applied Science and Manufacturing, 38(3), 925–935. https://doi.org/10.1016/J.COMPOSITESA.2006.07.004

11. Abdullahi, M., Oyetola, E. B., & Abdullahi, M. (n.d.). The Use of Rice Husk Ash in Low-Cost Sandcrete Block Production Leonardo Electronic Journal of Practices and Technologies The Use of Rice Husk Ash in Low-Cost Sandcrete Block Production. http://lejpt.academicdirect.org
12. Mohamed, R. M., Mkhalid, I. A., & Barakat, M. A. (2015). Rice husk ash as a renewable source for the production of zeolite NaY and its characterization. Arabian Journal of Chemistry, 8(1), 48–53. https://doi.org/10.1016/J.ARABJC.2012.12.013
13. Sukmana, H., Bellahsen, N., Pantoja, F., & Hodur, C. (2021). Adsorption and coagulation in wastewater treatment - Review. In Progress in Agricultural Engineering Sciences (Vol. 17, Issue 1, pp. 49–68). Akademiai Kiado ZRt. https://doi.org/10.1556/446.2021.00029
14. Afroze, S., Sen, T. K., & Ang, H. M. (2016). Adsorption removal of zinc (II) from aqueous phase by raw and base modified Eucalyptus sheathiana bark: Kinetics, mechanism and equilibrium study. Process Safety and Environmental Protection, 102, 336–352. https://doi.org/10.1016/J.PSEP.2016.04.009
15. Foo, K. Y., & Hameed, B. H. (2010). Insights into the modeling of adsorption isotherm systems. Chemical Engineering Journal, 156(1), 2–10. https://doi.org/10.1016/J.CEJ.2009.09.013
16. Saadi, A., Saadi Ibrahem, A., & Nor Ismail, K. (2012). An Overview Of Rice Husk Applications And Surface Modification Techniques In Wastewater Treatment An overview of rice husk applications and modification techniques in wastewater treatment Article Info. Journal of Purity, Utility Reaction and Environment, 1(6), 308–334. https://www.researchgate.net/publication/318455500
17. Tsai, W. T., Lin, Y. Q., & Huang, H. J. (2021). Valorization of rice husk for the production of porous biochar materials. Fermentation, 7(2). https://doi.org/10.3390/fermentation7020070
18. Fatima, I., Ahmad, M., Vithanage, M., & Iqbal, S. (2021). Abstraction of nitrates and phosphates from water by sawdust- and rice husk-derived biochars: Their potential as N- and P-loaded fertilizer for plant productivity in nutrient deficient soil. Journal of Analytical and Applied Pyrolysis, 155, 105073. https://doi.org/10.1016/J.JAAP.2021.105073
19. Bianchini, P., Merlo, F., Maraschi, F., Brescia, R., Prato, M., Profumo, A., & Speltini, A. (2023). From Rice Husk Ash to Silica-Supported Carbon Nanomaterials: Characterization and Analytical Application for Pre-Concentration of Steroid Hormones from Environmental Waters. Molecules, 28(2). https://doi.org/10.3390/molecules28020745
20. Shukla, N., Sahoo, D., & Remya, N. (2019). Biochar from microwave pyrolysis of rice husk for tertiary wastewater treatment and soil nourishment. Journal of Cleaner Production, 235, 1073–1079. https://doi.org/10.1016/J.JCLEPRO.2019.07.042
21. Elham, A., Hossein, T., & Mahnoosh, H. (2011). Removal of Zn(II) and Pb (II) ions Using Rice Husk in Food Industrial Wastewater. Journal of Applied Sciences and Environmental Management, 14(4). https://doi.org/10.4314/jasem.v14i4.63306
22. Chuah, T. G., Jumasiah, A., Azni, I., Katayon, S., & Thomas Choong, S. Y. (2005). Rice husk as a potentially low-cost biosorbent for heavy metal and dye removal: an overview. Desalination, 175(3), 305–316. https://doi.org/10.1016/J.DESAL.2004.10.014
23. Gargiulo, V., Di Natale, F., & Alfe, M. (2024). From agricultural wastes to advanced materials for environmental applications: Rice husk-derived adsorbents for heavy metals removal from wastewater. Journal of Environmental Chemical Engineering, 12(5), 113497. https://doi.org/10.1016/J.JECE.2024.113497
24. Shi, J., Fan, X., Tsang, D. C. W., Wang, F., Shen, Z., Hou, D., & Alessi, D. S. (2019). Removal of lead by rice husk biochars produced at different temperatures and implications for their environmental utilizations. Chemosphere, 235, 825–831. https://doi.org/10.1016/J.CHEMOSPHERE.2019.06.237
25. Russo, B., Causse, J., Rey, C., Lautru, J., Rebiscoul, D., & Ayral, A. (2023). Biosourced adsorbent prepared with rice husk part 1: A complete understanding of the structure of materials, the major role of mineral impurities for metal extraction. Sustainable Materials and Technologies, 36, e00601. https://doi.org/10.1016/J.SUSMAT.2023.E00601
26. Shi, W., Liu, C., Shu, Y., Feng, C., Lei, Z., & Zhang, Z. (2013). Synergistic effect of rice husk addition on hydrothermal treatment of sewage sludge: Fate and environmental risk of heavy metals. Bioresource Technology, 149, 496–502. https://doi.org/10.1016/J.BIORTECH.2013.09.114
27. Amen, R., Yaseen, M., Mukhtar, A., Klemeš, J. J., Saqib, S., Ullah, S., Al-Sehemi, A. G., Rafiq, S., Babar, M., Fatt, C. L., Ibrahim, M., Asif, S., Qureshi, K. S., Akbar, M. M., & Bokhari, A. (2020). Lead and cadmium removal from wastewater using eco-friendly biochar adsorbent derived from rice husk, wheat straw, and corncob. Cleaner Engineering and Technology, 1, 100006. https://doi.org/10.1016/J.CLET.2020.100006
28. Nabieh, K. A., Mortada, W. I., Helmy, T. E., Kenawy, I. M. M., & Abou El-Reash, Y. G. (2021). Chemically modified rice husk as an effective adsorbent for removal of palladium ions. Heliyon, 7(1), e06062. https://doi.org/10.1016/J.HELIYON.2021.E06062
29. Yefremova, S., Kablanbekov, A., Satbaev, B., & Zharmenov, A. (2023). Rice Husk-Based Adsorbents for Removal of Metals from Aqueous Solutions. In Materials (Vol. 16, Issue 23). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/ma16237353

30. Zhang, W., Duo, H., Li, S., An, Y., Chen, Z., Liu, Z., Ren, Y., Wang, S., Zhang, X., & Wang, X. (2020). An overview of the recent advances in functionalization biomass adsorbents for toxic metals removal. Colloid and Interface Science Communications, 38, 100308. https://doi.org/10.1016/J.COLCOM.2020.100308
31. Sarkar, D., Das, S. K., & Bandyopadhyay, A. (n.d.). Analysis of Bio-Sorption of Cr(VI) onto Raw Rice Husk by a Hybrid Theoretical Model Using Results of Batch Experiments.
32. Zulkali, M. M. D., Ahmad, A. L., & Norulakmal, N. H. (2006). Oryza sativa L. husk as heavy metal adsorbent: Optimization with lead as model solution. Bioresource Technology, 97(1), 21–25. https://doi.org/10.1016/J.BIORTECH.2005.02.007
33. Gandhimathi, R., Ramesh, S. T., & Praveeth, E. A. (n.d.). Adsorptive Removal of Copper from Aqueous Solution onto Raw Rice Husk: Kinetics and Isotherms.
34. Adekola, F. A., Hodonou, D. S. S., & Adegoke, H. I. (2016). Thermodynamic and kinetic studies of biosorption of iron and manganese from aqueous medium using rice husk ash. Applied Water Science, 6(4), 319–330. https://doi.org/10.1007/s13201-014-0227-1
35. Georgieva, V. G., Tavlieva, M. P., Genieva, S. D., & Vlaev, L. T. (2015). Adsorption kinetics of Cr(VI) ions from aqueous solutions onto black rice husk ash. Journal of Molecular Liquids, 208, 219–226. https://doi.org/10.1016/J.MOLLIQ.2015.04.047
36. Naiya, T. K., Bhattacharya, A. K., Mandal, S., & Das, S. K. (2009). The sorption of lead(II) ions on rice husk ash. Journal of Hazardous Materials, 163(2–3), 1254–1264. https://doi.org/10.1016/J.JHAZMAT.2008.07.119
37. Krishnani, K. K., Meng, X., Christodoulatos, C., & Boddu, V. M. (2008). Biosorption mechanism of nine different heavy metals onto biomatrix from rice husk. Journal of Hazardous Materials, 153(3), 1222–1234. https://doi.org/10.1016/J.JHAZMAT.2007.09.113
38. Rajput, R. S., Singh, M., Kumar, P., & Srivastava, N. K. (2022). EVALUATION OF DAIRY EFFLUENT DETOXIFICATION AND REMOVAL EFFICIENCY IN AN INTEGRATED WASTEWATER TREATMENT SYSTEM USING LOW-COST ADSORBENTS. Rasayan Journal of Chemistry, 15(1), 593–599. https://doi.org/10.31788/RJC.2022.1516727
39. Vincet, A., Abdul Rahim, M., Shukor, Y., & Bin Khayat, M. (2024). Optimisation of casein adsorption onto alkaline-treated rice husk using response surface methodology for sustainable protein recovery. ResearchGate.
40. Tanvir Arfin, S. S. W. (2015). Fluoride Removal from Water By Calcium Materials: A State-Of-The-Art Review. International Journal of Innovative Research in Science, Engineering and Technology, 4(9), 8090–8102. https://doi.org/10.15680/ijirset.2015.0409013
41. Sharmin, N., Sabatini, D. A., & Butler, E. C. (2021). Phosphorus Recovery and Reuse Using Calcium-Silicate Hydrate Made from Rice Husk. Journal of Environmental Engineering, 147(6). https://doi.org/10.1061/(asce)ee.1943-7870.0001877
42. Mankomal, & Kaur, H. (2022). Rice straw biochar for removal of phenol from water. Journal of Physics: Conference Series, 2267(1). https://doi.org/10.1088/1742-6596/2267/1/012129
43. Lap, B. Q., Thinh, N. V. D., Hung, N. T. Q., Nam, N. H., Dang, H. T. T., Ba, H. T., Ky, N. M., & Tuan, H. N. A. (2021). Assessment of Rice Straw–Derived Biochar for Livestock Wastewater Treatment. Water, Air, and Soil Pollution, 232(4). https://doi.org/10.1007/s11270-021-05100-8
44. Rayabharapu, V. K., Manjunatha, B., Petluru, P., & Mella, B. S. (2024). Treatment of wastewater using rice husk ash. IOP Conference Series: Earth and Environmental Science, 1409(1). https://doi.org/10.1088/1755-1315/1409/1/012033
45. Gudadhe Khatri Mahavidyalaya, S., & Gudadhe, S. K. (2022). Rice Husk is use to Treatment of Gray Water. International Journal of Advanced Research in Biological Sciences, 9(1), 96–99. https://doi.org/10.22192/ijarbs
46. Costa-Conceicao, K., Ayala, C. A. V., Dávila, T., & Gallardo, M. C. (2023). Performance of hybrid biofilter based on rice husks/sawdust treating grey wastewater. Water Science and Technology, 87(10), 2416–2431. https://doi.org/10.2166/wst.2023.132
47. Lv, S., Chen, X., Ye, Y., Yin, S., Cheng, J., & Xia, M. (2009). Rice hull/MnFe2O4 composite: Preparation, characterization and its rapid microwave-assisted COD removal for organic wastewater. Journal of Hazardous Materials, 171(1–3), 634–639. https://doi.org/10.1016/J.JHAZMAT.2009.06.039
48. Lugo-Arias, J., Vargas, S. B., Maturana, A., González-Álvarez, J., Lugo-Arias, E., & Rico, H. (2024). Nutrient Removal from Aqueous Solutions Using Biosorbents Derived from Rice and Corn Husk Residues: A Systematic Review from the Environmental Management Perspective. In Water (Switzerland) (Vol. 16, Issue 11). Multidisciplinary Digital Publishing Institute (MDPI). https://doi.org/10.3390/w16111543
49. Nnaji, C. C., Mama, C. N., Ezekoye, D. A., & Iwuchukwu, I. (2017). Coagulation and clarification of wastewater using rice husk ash. Desalination and Water Treatment, 72, 266–273. https://doi.org/10.5004/DWT.2017.20423
50. Mortada, W. I., Mohamed, R. A., Monem, A. A. A., Awad, M. M., & Hassan, A. F. (2023). Effective and Low-Cost Adsorption Procedure for Removing Chemical Oxygen Demand from Wastewater Using Chemically Activated Carbon Derived from Rice Husk. Separations, 10(1). https://doi.org/10.3390/separations10010043

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XIV, Issue VI, June 2025

51. Huong, P. T., Jitae, K., Al Tahtamouni, T. M., Le Minh Tri, N., Kim, H. H., Cho, K. H., & Lee, C. (2020). Novel activation of peroxymonosulfate by biochar derived from rice husk toward oxidation of organic contaminants in wastewater. Journal of Water Process Engineering, 33. https://doi.org/10.1016/j.jwpe.2019.101037
52. Seroja, R., Effendi, H., & Hariyadi, S. (2018). Tofu wastewater treatment using vetiver grass (Vetiveria zizanioides) and zeliac. Applied Water Science, 8(1). https://doi.org/10.1007/s13201-018-0640-y
53. IJCHE_Volume 3_Issue 3_Pages 44-50 (1). (n.d.).
54. Scaglioni, P. T., & Badiale-Furlong, E. (2016). Rice husk as an adsorbent: A new analytical approach to determine aflatoxins in milk. Talanta, 152, 423–431. https://doi.org/10.1016/J.TALANTA.2016.02.042
55. Lakshmi, U. R., Srivastava, V. C., Mall, I. D., & Lataye, D. H. (2009). Rice husk ash as an effective adsorbent: Evaluation of adsorptive characteristics for Indigo Carmine dye. Journal of Environmental Management, 90(2), 710–720. https://doi.org/10.1016/J.JENVMAN.2008.01.002
56. Nguyen Thi, T., Tran Dang Lan, V., Nguyen Xuan, H., Le Thi Bich, S., Tran Thi Ngoc, M., Dang Van, T., & Nguyen Nhat, H. (2020). STUDY ON THE REMOVAL OF AMMONIA IN WASTEWATER USING ADSORBENT PREPARED FROM RICE HULL WITH MAGNESIUM OXIDE MODIFICATION. Vietnam Journal of Science and Technology, 58(3A), 113. https://doi.org/10.15625/2525-2518/58/3a/14322