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GREEN SYNTHESIS AND MODIFICATION OF ADSORBENTS FOR WATER TREATMENT APPLICATIONS

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INTRODUCTION

The removal of inorganic ions from contaminated water is an important challenge in the development of efficient, sustainable and economically feasible water treatment technologies. Adsorption is widely investigated because of its operational simplicity, high removal efficiency and the possibility of designing adsorbents with specific surface properties.

In recent years, increasing attention has been directed towards natural and renewable lignocellulosic materials obtained from agricultural and food-processing residues. The most frequently investigated raw materials include cellulose, lignin, hemicellulose, sawdust, rice husk, wheat straw, corn stalks and cobs, sugarcane bagasse, coconut residues, fruit peels and other agro-industrial by-products. These materials are attractive because of their abundance, low cost, biodegradability and high potential for valorisation.

Their surfaces contain functional groups such as hydroxyl, carboxyl, phenolic and methoxy groups, which can interact with inorganic ions through ion exchange, electrostatic attraction, surface complexation and, in some cases, precipitation.

However, untreated lignocellulosic materials may exhibit relatively low adsorption capacity, limited selectivity, swelling, hydrophilicity and insufficient mechanical stability. Consequently, physical and chemical modification has become one of the most important strategies for improving their adsorption performance. Common modification approaches include alkaline or acidic treatment, oxidation, esterification, phosphorylation, graft polymerisation, amination, cross-linking, impregnation with metal oxides and incorporation of magnetic particles. These treatments can increase porosity and surface area, expose existing functional groups or introduce new active binding sites.

Particularly promising results have been reported for modified lignocellulosic materials used for the removal of Pb(II), Cd(II), Cu(II), Zn(II), Ni(II), Hg(II), Cr(VI), As(V/III), phosphate and nitrate ions. Metal-oxide modification, amino-functionalisation and grafting with chelating groups can substantially improve both adsorption capacity and selectivity. For example, magnetite modification of sawdust increased Zn(II) removal to almost 99%, while functionalised cellulose and sawdust have demonstrated high capacities for Hg(II), Pb(II), Cu(II) and As(V).

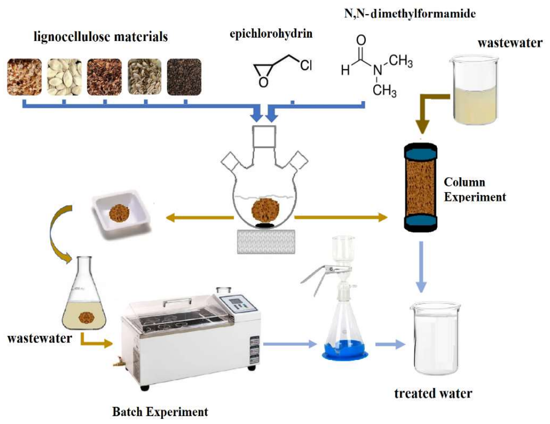

Figure 1. Steps of adsorbent modification and testing

Table 1. Reported efficiencies of modified adsorbents for inorganic ions removal

Ion	Modified lignocellulosic adsorbent	Modification	Maximum removal (%)	Reference
Pb^{2+}	Rice husk biochar	Fe_3O_4/ZnO + deep eutectic solvent	99.4	Sui et al., 2026
Cd^{2+}	Alkali-treated sunflower husk	NaOH activation	96.2	Sui et al., 2026
Cu^{2+}	Phosphate-functionalized lignocellulosic biomass	Phosphate grafting	97.6	Guo et al., 2024
Zn^{2+}	Aminated lignocellulosic residue	Amine grafting	93.8	Guo et al., 2024
Ni^{2+}	Rice husk ash silica	Fe_3O_4@SiO_2–TMPDT	94.5	Hastuti et al., 2025
Hg^{2+}	Sulfur-modified cellulose	Thiol functionalization	98.2	Shabbirahmed et al., 2025
Cr^{4+}	Rice husk biochar	Fe_3O_4/ZnO + DES	98.9	Sui et al., 2026
As^{5+}	Iron-loaded cellulose	Fe impregnation	97.4	Abdelrhman et al., 2026
As^{3+}	Fe-modified lignin composite	Iron oxide coating	95.6	Tarkar et al., 2026
PO_4^{3-}	Lanthanum-modified cellulose	Lanthanum coating	99.1	Nature-based hybrid adsorbents, 2025
NO_3^-	Quaternized cellulose	Quaternary ammonium groups	95.0	Abdelrhman et al., 2026

CONCLUSION

Modified lignocellulosic materials are promising sustainable adsorbents for removing inorganic ions from aqueous systems. Their advantages include the abundance, renewability and low cost of lignocellulosic biomass, as well as the presence of reactive functional groups.

Materials such as cellulose, lignin, sawdust, rice husk, wheat straw, corn residues and sugarcane bagasse have shown potential for removing heavy metals and inorganic oxyanions. Surface modification can significantly enhance adsorption performance by introducing carboxyl, amino or phosphate groups and incorporating Fe, Mg, Ca, Zr or magnetic phases. High removal efficiencies have been reported for ions such as Pb(II), Hg(II), Cu(II), Zn(II) and Cr(VI).

However, practical applicability depends not only on removal efficiency but also on regeneration and reuse, stability, possible leaching, selectivity, cost and performance in real wastewater. Since many studies still use single-ion solutions, further research should address competitive adsorption in complex water matrices.

Future efforts should focus on low-cost, multifunctional and regenerable lignocellulosic adsorbents validated under realistic conditions. Their application could combine pollutant removal with biomass valorisation, resource recovery and circular economy principles.

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