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Enhanced Phosphate Adsorption Using Metal-Impregnated Coconut Coir Biochar: A Comparative Study of Al and Mg Modification

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Excess phosphate in aquatic systems is a major environmental concern, creating a need for efficient and sustainable adsorbents for nutrient removal. This study investigated the phosphate adsorption performance of pristine, Mg-modified, and Al-modified biochar derived from coconut coir, highlighting the potential of low-cost agricultural waste for water treatment applications. The novelty of this work lies in the comparative evaluation of Mg- and Al-impregnated coconut coir biochars and the relationship between their surface properties and phosphate adsorption behavior. Biochars were synthesized by pyrolyzing chemically treated coconut coir at 500 °C under nitrogen. The materials were characterized using pH at point of zero charge (pHPZC), methylene blue adsorption, iodine number, and FTIR spectroscopy to evaluate surface charge, porosity, and functional groups. FTIR analysis confirmed successful hydroxyl, aliphatic C–H, carbonyl, and aromatic C=C groups, along with metal loading through the presence of Mg–O and Al–O functional groups (~500–800 cm^{-1}), which provided additional active sites for phosphate adsorption. Pristine biochar exhibited moderate adsorption properties with limited microporosity (pHPZC = 8.98, MB value = 35.87 mg/g, iodine number = 69.39 mg/g). Mg-modified biochar showed increased pHPZC (10.15) and significantly enhanced microporosity (iodine number = 274 mg/g); however, its lower mesoporosity (MB number = 24.16 mg/g) reduced phosphate accessibility to active sites, resulting in relatively poor phosphate removal (13–16% over pH 2–8). In contrast, Al-modified biochar demonstrated superior adsorption performance, achieving a maximum phosphate removal of 81.5% at pH 8. The enhanced performance was attributed to favorable electrostatic interactions and the formation of stable aluminium–phosphate complexes. Overall, the results demonstrate that metal modification strongly influences the phosphate adsorption behavior of coconut coir biochar. Among the tested materials, Al-modified biochar showed the highest phosphate removal efficiency, indicating its potential as a selective, sustainable, and low-cost adsorbent for nutrient remediation in water treatment systems.

Keywords:

Mg- and Al-impregnated biochar; Phosphate removal; Coconut coir; Water treatment; Sustainable adsorbents.

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