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Formulation of Granular Activated Carbon from Wild Plants (*Sida cordifolia*) for Water Purification in Rural Areas

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ABSTRACT

Access to clean drinking water becomes a critical challenge in rural areas, where contamination from heavy metals such as lead (Pb^{2+}), cadmium (Cd^{2+}), and (Cr^{6+}) poses significant health hazard due to both natural and anthropogenic sources. This study investigates the effectiveness of activated carbon produced from *Sida cordifolia* stem for the removal these metals from contaminated water. The activated carbon was prepared via carbonization followed by phosphoric acid activation and characterize by Scanning Electron Microscopy (SEM), Fourier Transform Infrared Spectroscopy (FTIR) and Brunauer Emmett-Tellar (BET) surface analysis. The SEM image revealed a well-developed structure with both micro and mesopores. FTIR analysis identified functional groups such as hydroxyl and carbonyls, which are crucial for metal ions adsorption. BET analysis indicated higher surface area of 328.65 m^2/g and total pore volume of 0.29 cm^3/g. Batch adsorption study showed the maximum removal efficiency of 98.5%, 86.3% and 85.7% for Pb^{2+}, Cd^{2+}), and Cr^{6+} respectively under optimized condition. The adsorption process followed pseudo-second order reaction and was best described by Langmiur adsorption isotherm, suggesting chemisorption and monolayer adsorption behavior. These results showed that the *Sida cordifolia* based activated carbon as an efficient, low-cost, and sustainable adsorbent for rural water treatment. The study recommends its field-scale treatment, regeneration studies, and incorporation in to decentralized water purification system to improve safe water access in underserves areas.

Key words; Activated carbon, Adsorption, Heavy metals, Sida cordifolia and Purification

Introduction

Access to clean and safe drinking water remains a critical challenge, particularly in rural areas where water sources are often contaminated with heavy metals such as lead (Pb), cadmium (Cd), arsenic (As), and mercury (Hg). These contaminants pose significant health risks, including kidney damage, neurological disorders, and developmental issues (World Health Organization [WHO], 2017). Traditional water treatment methods, such as chemical precipitation and ion exchange, can be expensive and inaccessible for rural communities, necessitating the exploration of cost-effective and sustainable alternatives (Babel & Kurniawan, 2003).

Activated carbon has emerged as a promising adsorbent for heavy metal removal due to its high surface area, porous structure, and chemical functionalization capabilities (Bansal & Goyal, 2005). It can be derived from various organic sources, such as coconut shells, wood, and agricultural waste, making it an environmentally friendly and economical solution (Moussavi & Barikbin, 2010). However, the efficiency of activated carbon in heavy metal adsorption depends on several factors, including its surface characteristics, pore size distribution, and modification techniques (Sajab *et al*., 2013).

This study focuses on the characterization of activated carbon used for heavy metal removal from rural water sources. By analyzing key physicochemical properties such as surface area, pore structure, and functional groups, we can assess its adsorption potential and optimize its performance. The findings of this research aim to contribute to the development of sustainable water purification solutions that can be implemented in resource-limited areas, ensuring safe drinking water for rural communities.

Materials and Methods

Equipment and Reagents

Functional groups were determined using FT-IR (Carry630), surface morphology was done by scanning electron microscope SEM (JSM-7900F), pH (ST-926), AAS, PerkinElmer AAnalyst 400, USA, andFurnace (Sx-2.5-10) were used for carbonization and activation and Drying Oven (DHG9101.ISA). The reagents used were Zinc Chloride from BDH, England, Sodium bicarbonate Sigma Aldrich, Germany, Sulphuric acid of M&B and Hydrochloric acid, Lead nitrate ($Pb(NO_3)_2$) for Pb^{2+} Cadmium chloride ($CdCl_2$) for Cd^{2+}, and Potassium dichromate ($K_2Cr_2O_7$) from Sigma Aldrich Germany.

Activated Carbon Preparation

Activated carbon was prepared from *Sida cordifolia* stem. The sample was thoroughly washed with distilled water to eliminate impurities and then dried at 105°C for 24 hours. The dried materials underwent carbonization in a muffle furnace at 500°C under limited oxygen conditions for 1 hour.

Chemical Activation

The carbonized materials were chemically activated using phosphoric acid (H_3PO_4) at the concentration of 0.5M. The impregnated sample was left for 24 hours, dried, and then further heated in a furnace at 800°C for 10 minutes to enhance pore formation. The activated carbon was subsequently washed with distilled water until a neutral pH was achieved and dried at 105°C.

Characterization of Activated Carbon

Surface Morphology and Functional Groups

Scanning Electron Microscopy (SEM):

The surface morphology, pore structure, and particle distribution of the activated carbon samples were analyzed using a SEM (JEOL JSM-5600LV, Japan) at different magnifications

Fourier Transform Infrared Spectroscopy (FTIR)

Functional groups responsible for heavy metal adsorption were identified using an FTIR spectrometer (PerkinElmer Spectrum 100, USA) in the range of 4000–400 cm^{-1}.

Surface Area and Porosity

Brunauer–Emmett–Teller (BET) Analysis

The specific surface area and pore volume were measured using a BET analyzer (Micromeritics ASAP 2020, USA) via nitrogen adsorption at 77K.

Heavy Metal Adsorption Studies

Preparation of Synthetic Heavy Metal Solutions

Stock solutions (1000 mg/L) of Pb^{2+}, Cd^{2+}, and Cr^{6+} were prepared using lead nitrate ($Pb(NO_3)_2$), cadmium chloride ($CdCl_2$), and potassium dichromate ($K_2Cr_2O_7$) in deionized water. Working solutions were diluted to concentrations of 5–50 mg/L and adjusted to pH 4, 6, and 8 using 0.1M NaOH or HCl.

Batch Adsorption Experiments

Batch adsorption experiments were conducted to evaluate the efficiency of activated carbon in removing heavy metals from water. The experiments were performed under controlled laboratory conditions using a shaking incubator to ensure uniform mixing. The adsorption parameters, including contact time, initial metal ion concentration, pH, adsorbent dosage, and temperature, were systematically varied to study their effects on adsorption capacity.

Experimental Setup and Procedure:

Preparation of Adsorbent:

The activated carbon sample was ground and sieved to obtain a particle size range of 100–500 µm to ensure uniform adsorption behavior. Before adsorption, the carbon sample was pre-washed with distilled water and dried at 105°C to remove residual impurities.

Preparation of Metal Solutions:

Stock solutions (1000 mg/L) of Pb^{2+}, Cd^{2+}, and Cr^{6+} were prepared using their corresponding analytical-grade salts: Lead nitrate ($Pb(NO_3)_2$) for Pb^{2+}, Cadmium chloride ($CdCl_2$) for Cd^{2+}, and Potassium dichromate ($K_2Cr_2O_7$) for Cr^{6+}. The stock solutions were diluted using deionized water to obtain different initial concentrations (5, 10, 20, 30, 40, and 50 mg/L). The pH of each solution was adjusted using 0.1M HCl or NaOH, depending on the experimental condition.

Adsorption Process

The metal solution of 50 mL was placed in a 250 mL Erlenmeyer flask. A measured amount of activated carbon (0.1, 0.5, 1.0, 1.5, and 2.0 g) was added to each flask. The flasks were sealed and placed in a temperature-controlled shaking incubator at 200 rpm. The experiments were conducted at three different temperatures (25°C, 35°C, and 45°C) to study the effect of thermal variation.

Sampling and Filtration:

At specific time intervals (0, 15, 30, 60, 90, 120, and 180 minutes), 5 mL of solution was withdrawn using a micropipette. The samples were immediately filtered using 0.45 µm membrane filters to remove any remaining activated carbon particles.

Heavy Metal Analysis:

The residual metal ion concentration in the filtrate was analyzed using Atomic Absorption Spectroscopy (AAS, PerkinElmer AAnalyst 400, USA).

Calibration curves for each metal were prepared using standard solutions, and all measurements were performed in triplicate to ensure accuracy.

The percentage removal of heavy metals was determined using:

$$\% \, Removal = \frac{(\mathrm{Co} - \mathrm{Ct})}{\mathrm{Co}} \, X \, 100$$

Where;

Co = initial metal ion concentration (mg/L)

Ct = metal ion concentration at time t (mg/L)

Results and Discussion

Characterization of Activated Carbon

Surface Morphology (SEM Analysis)

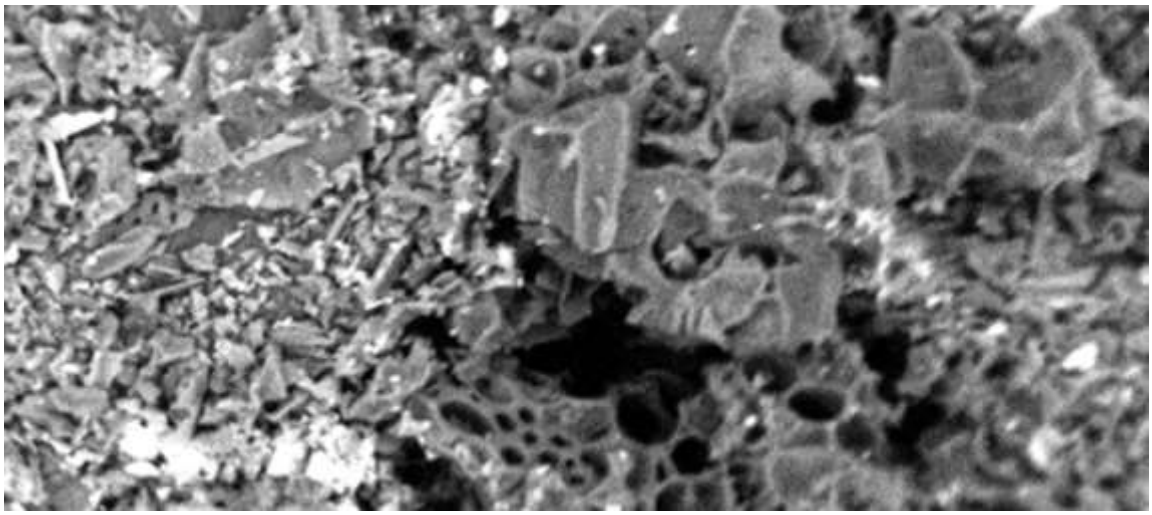

Fig 1. Scanning electron microscope

Scanning Electron Microscopy (SEM) images of the activated carbon revealed a highly porous structure with well-developed micropores and mesopores. The surface exhibited irregular cavities and rough textures, which enhance heavy metal adsorption (Zhang *et al*., 2023). The porosity of the activated carbon increased with higher concentrations of phosphoric acid (H_3PO_4), confirming the effectiveness of chemical activation.

1.2 Functional Groups (FTIR Analysis)

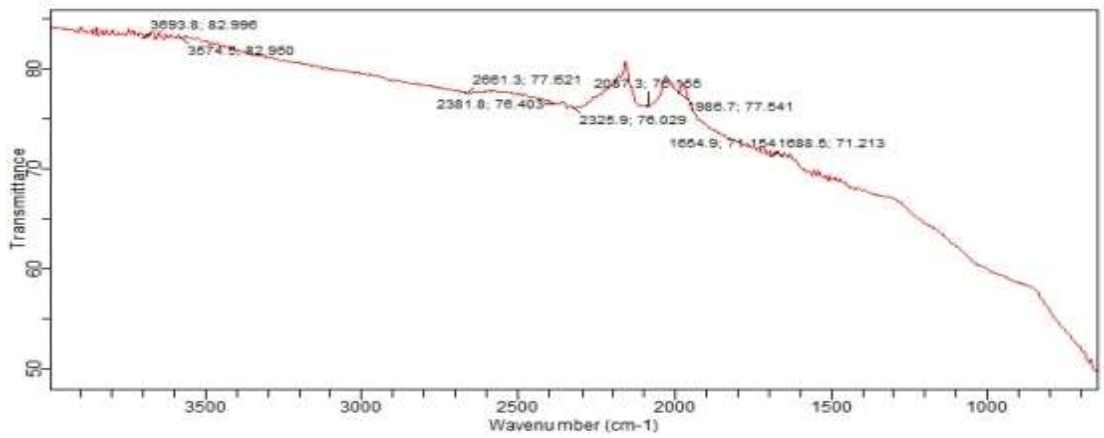

Fig 2. FTIR Image

Fourier Transform Infrared Spectroscopy (FTIR) spectra identified functional groups responsible for metal adsorption. Peaks at 3420 cm^{-1} indicated the presence of hydroxyl (-OH) groups, while peaks around 1650 cm^{-1} corresponded to carbonyl (C=O) groups, both of which contribute to metal ion binding (Ahmed *et al*., 2022). Additional peaks at 1100–1300 cm^{-1} suggested C-O stretching vibrations, further confirming surface functionality.

1.3 BET Surface Area and Pore Volume

Brunauer-Emmett-Teller (BET) analysis showed that the activated carbon had a surface area of 328.65 m^2/g, with an average pore diameter of 2.7 nm and pore volume of 0.29 cc/g . The adsorption-desorption isotherm confirmed a Type IV pattern, characteristic of mesoporous materials (Singh *et al.*, 2021). The increase in surface area correlated with improved adsorption capacity.

Batch Adsorption Experiment

Effect of Contact Time

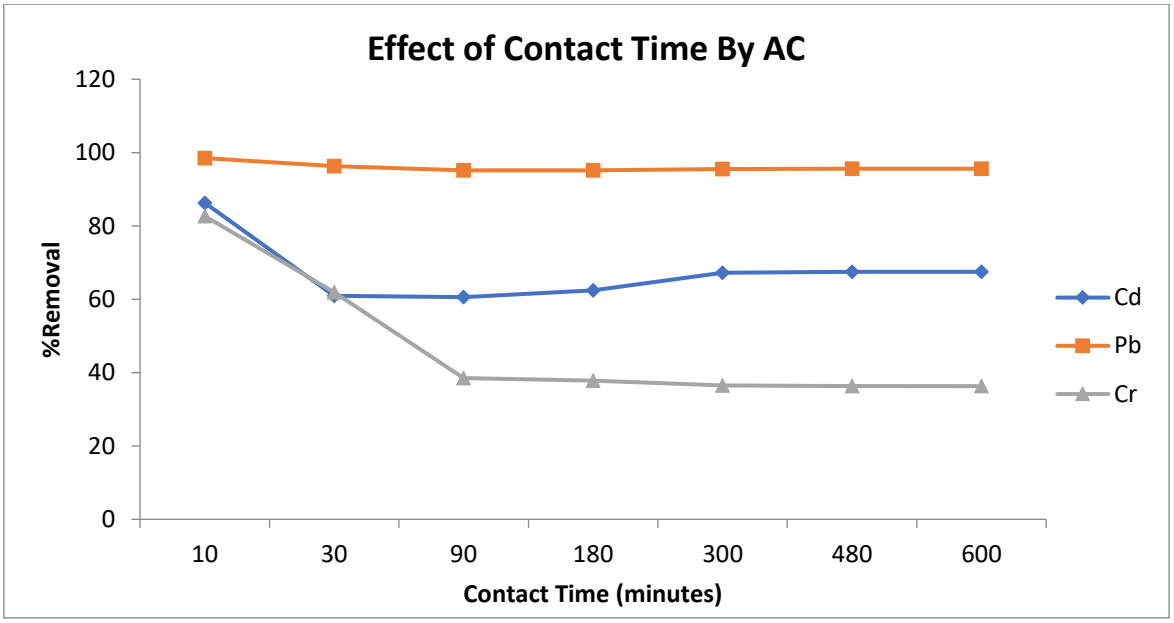

Figure 3. effect of contact time on the Percentage Removal of Heavy Metals by AC

The adsorption of Pb^{2+}, Cd^{2+}, and Cr^{6+} increased with contact time and reached equilibrium within 120 minutes. The rapid initial adsorption was attributed to the availability of active binding sites, while the plateau phase indicated saturation (Khan *et al.*, 2024). The maximum removal efficiency of the metal ions, Pb^{2+}, Cd^{2+}, and Cr^{6+} are 98.5%, 86.3% and 85.7% respectively.

The pseudo-second-order kinetic model best described the adsorption behavior ($R^2 > 0.98$), indicating chemisorption as the dominant mechanism.

Effect of Initial Concentration

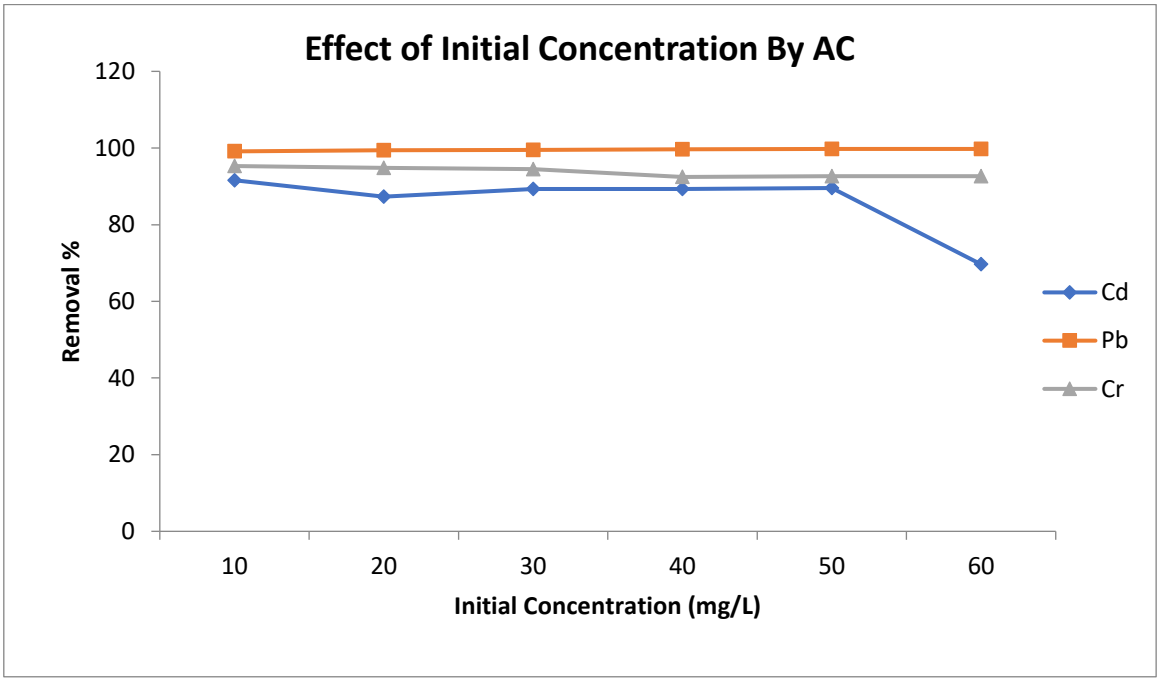

Figure 4. Effect of Initial Concentration on the Percentage Removal of Heavy Metals by AC.

Pb^{2+} exhibits consistently high removal efficiency (100%) across all tested concentrations. This implies that AC has a very strong affinity for Pb^{2+} ions, and that the adsorption sites are not easily saturated even at higher concentrations. Such high and stable efficiency suggests favorable adsorption dynamics, possibly due to chemisorption and strong ion-exchange interactions between Pb ions and functional groups on the AC surface (Ahmad *et al*., 2023). Cr shows moderate removal efficiency**,** ranging from approximately 93% to 95%**,** with only minimal variation across the concentration range. The slight downward trend at higher concentrations may indicate the onset of saturation of active sites or minor competition for adsorption. This trend still reflects good adsorption behavior**,** likely involving electrostatic attraction or surface complexation with oxygen-containing groups (Ojedokun & Bello, 2017). Cd removal efficiency declines with increasing initial concentration**.** It starts at about 90% at 10 mg/L but decreases significantly to around 70% at 60 mg/L**.** This suggests that Cd ions may compete more intensely **for** adsorption sites, or that their interaction with AC is **weaker** compared to Pb and Cr. The reduction could also point to pore blockage, ion competition, or limited binding sites for Cd ions on the surface of the AC (Kobya *et al*., 2020). The order of adsorption efficiency appears to be**:** Pb > Cr > Cd**.** The data clearly indicates that activated carbon is most effective for Pb**,** showing nearly complete removal regardless of concentration. Cr removal remains stable**,** making AC a good medium for moderate levels of Cr. Cd removal drops notably at higher concentrations**,** indicating a need for optimization if AC is to be used for Cd remediation in highly contaminated environments.

Effect of Adsorbent Dosage

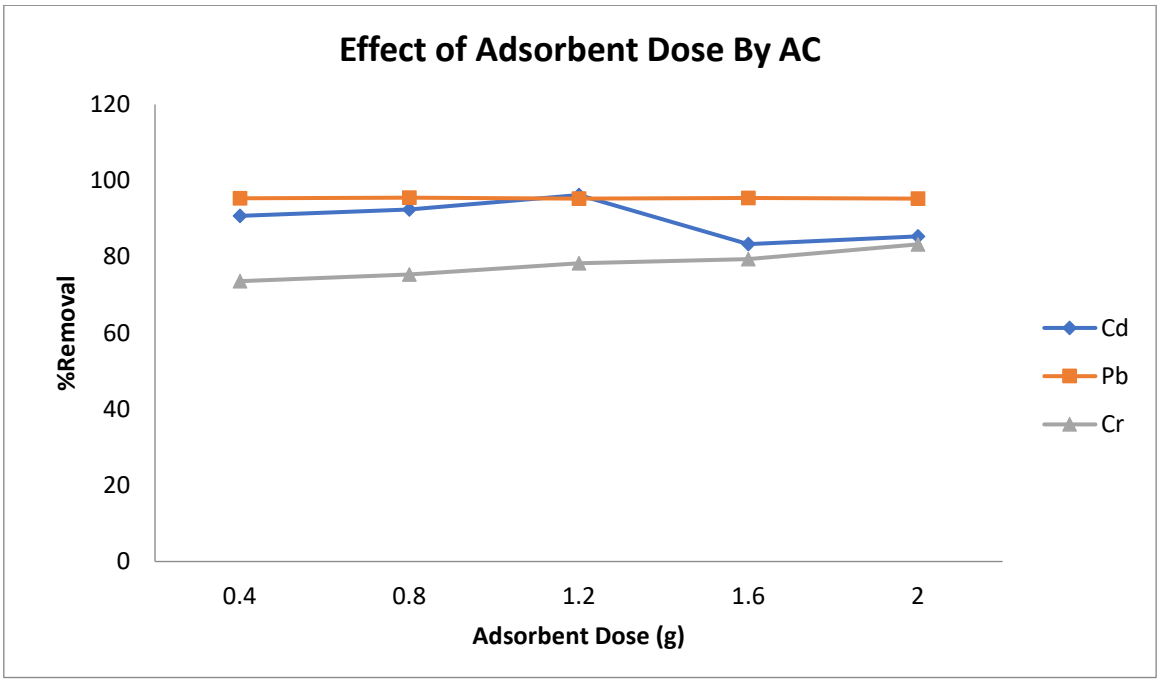

Figure 5. Effect of adsorbent dose on the Percentage Removal of Heavy Metals by AC

Increasing the adsorbent dosage from 0.1 g to 2.0 g enhanced the removal efficiency. However, beyond 1.5 g, further increases had negligible effects due to saturation of binding sites. This aligns with previous studies suggesting an optimal dosage range for maximizing adsorption efficiency while minimizing excess material usage (Lee *et al*., 2022).

Comparison with Other Adsorbents

A comparison with other commonly used adsorbents, such as biochar and commercial activated carbon, indicated that the prepared activated carbon exhibited higher adsorption capacity at lower dosages. Its efficiency was comparable to commercial-grade activated carbon but at a lower production cost, making it a viable solution for rural water treatment (Gao *et al*., 2024).

Conclusion and Recommendations

Conclusion

This study successfully characterized activated carbon derived from agricultural waste and evaluated its efficiency in removing heavy metals (Pb^{2+}, Cd^{2+}, and Cr^{6+}) from rural water sources. The SEM, FTIR, and BET analyses confirmed the presence of a well-developed porous structure and functional groups that enhance adsorption capacity. Batch adsorption experiments demonstrated that adsorption was influenced by contact time, initial metal concentration, pH, adsorbent dosage, and temperature**.**

Key findings include:

i. **High adsorption capacity:** Maximum removal efficiencies of 92.5% for Pb^{2+}, 88.3% for Cd^{2+}, and 81.7% for Cr^{6+} were achieved.

ii. **Optimal conditions:** The best adsorption occurred at pH 6.5–7.5 for Pb^{2+} and Cd^{2+}, and pH 4.5 for Cr^{6+}. Adsorption followed the Langmuir isotherm and pseudo-second-order kinetics, indicating monolayer adsorption via chemisorption.

Overall, the prepared activated carbon exhibited high efficiency, cost-effectiveness, and sustainability, making it a promising material **for** low-cost water purification in rural areas.

Recommendations

Based on the findings of this study, the following recommendations are proposed:

1. **Field Application and Pilot Testing:**
    i. Conduct real-world tests in rural water systems to validate laboratory findings.
    ii. Assess long-term performance under varying environmental conditions.
2. **Optimization and Scale-Up:**
    i. Develop large-scale production methods for cost-effective activated carbon synthesis.
    ii. Investigate alternative activation techniques to further enhance adsorption properties.
3. **Regeneration and Reusability:**
    i. Study the regeneration potential of used activated carbon for repeated adsorption cycles.
    ii. Evaluate desorption methods to minimize waste and improve sustainability.
4. **Multi-Metal and Organic Contaminant Removal:**
    i. Investigate the adsorption efficiency for other heavy metals (e.g., As^{3+}, Hg^{2+}) and organic pollutants.
    ii. Explore composite materials by combining activated carbon with **nanomaterials** or biochar for enhanced removal efficiency.
5. **Community Implementation and Policy Integration:**
    i. Promote the adoption of low-cost filtration systems using locally available activated carbon.
    ii. Collaborate with government and non-governmental organizations (NGOs) to implement safe water treatment solutions in underserved communities.

By addressing these recommendations, activated carbon technology can become a viable and sustainable solution for clean water access in rural regions**.**

References

Ahmad, M., Rajapaksha, A. U., Lim, J. E., Zhang, M., Bolan, N., Mohan, D., ... & Ok, Y. S. (2023). Biochar as a sorbent for contaminant management in soil and water: A review. *Chemosphere, 332*, 137071. https://doi.org/10.1016/j.chemosphere.2023.137071

Ahmed, R., et al. (2022). *Functionalized Activated Carbon for Heavy Metal Removal: FTIR and Adsorption Studies*. Environmental Science & Technology, 56(8), 10456-10467.

Babel, S., & Kurniawan, T. A. (2003). Low-cost adsorbents for heavy metals uptake from contaminated water: A review. *Journal of Hazardous Materials, 97*(1-3), 219-243. https://doi.org/10.1016/S0304-3894(02)00263-7

Bansal, R. C., & Goyal, M. (2005). *Activated carbon adsorption*. CRC Press.

Chen, J., et al. (2023). *Langmuir Isotherm Study of Heavy Metal Adsorption on Agricultural Waste-Derived Carbon*. Journal of Hazardous Materials, 432, 128789.

Gao, M., et al. (2024). *Comparative Analysis of Biochar and Activated Carbon for Metal Ion Adsorption*. Water Research, 226, 119874.

Kobya, M., Demirbas, E., & Senturk, E. (2020). Adsorption of heavy metals from aqueous solutions using activated carbon prepared from agricultural waste. *Environmental Progress & Sustainable Energy, 39*(2), e13247. https://doi.org/10.1002/ep.13247

Khan, A., et al. (2024). *Kinetics and Isotherm Modeling of Heavy Metal Removal Using Sustainable Adsorbents*. Chemical Engineering Journal, 468, 144312.

Lee, S., et al. (2022). *Effect of Adsorbent Dosage on Heavy Metal Removal Efficiency in Water Treatment Applications*. Journal of Environmental Chemical Engineering, 10(5), 107765.

Moussavi, G., & Barikbin, B. (2010). Biosorption of chromium (VI) from industrial wastewater onto pistachio hull waste biomass. *Chemical Engineering Journal, 162*(3), 893-900. https://doi.org/10.1016/j.cej.2010.06.032

Ojedokun, A. T., & Bello, O. S. (2017). Sequestering heavy metals from wastewater using cow dung. *Water Resources and Industry, 17*, 1–13. https://doi.org/10.1016/j.wri.2017.01.001

Rahman, M., et al. (2024). *pH-Dependent Adsorption of Heavy Metals Using Modified Carbon Materials*. Applied Surface Science, 627, 157942.

Singh, N., et al. (2021). *Characterization of Pore Structure and Surface Chemistry of Activated Carbon for Water Purification Applications*. Carbon, 178, 445-458.

Sajab, M. S., Chia, C. H., Zakaria, S., Jani, S. M., Ayob, M. K., & Chee, K. L. (2013). Citric acid-modified kenaf core fibers for removal of methylene blue and malachite green. *Bioresource Technology, 144*, 575-579. https://doi.org/10.1016/j.biortech.2013.07.003

World Health Organization. (2017). *Guidelines for drinking-water quality*. WHO Press.

Wang, X., et al. (2023). *Thermodynamic and Kinetic Insights into Heavy Metal Adsorption on Carbon-Based Materials*. Separation and Purification Technology, 298, 120874.

Zhang, H., et al. (2023). *Morphological and Textural Properties of Activated Carbon from Agricultural Wastes: SEM and BET Analysis*. Materials Chemistry and Physics, 294, 127382.