International Journal for Multidisciplinary Research (IJFMR)

E-ISSN: 2582-2160 ● Website: www.ijfmr.com ● Email: editor@ijfmr.com

Household Waste Water Treatment Using Activated Charcoal: An Effective and Sustainable Approach

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Abstract:
Effective household wastewater management is crucial for environmental sustainability and public health, especially in areas with limited advanced treatment infrastructure. This study explores the use of activated charcoal as a cost-effective and efficient method for treating household wastewater. Known for its high adsorption capacity, activated charcoal was evaluated for its ability to remove key contaminants from wastewater collected from residential sources such as kitchens, bathrooms, and laundry areas.

The research utilized both batch adsorption tests and column filtration experiments. In the batch tests, wastewater samples were treated with varying doses of activated charcoal (2, 5, 10, and 15 g/L) over different contact times (30 minutes to 4 hours). The results showed that activated charcoal effectively reduced Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD), with average reductions of 75%, 65%, and 70%, respectively. Additionally, activated charcoal demonstrated significant effectiveness in removing heavy metals and organic compounds, with removal efficiencies ranging from 60% to 80% depending on the contaminant type and operational conditions. The optimal treatment conditions were found to be a dosage of 10 g/L and a contact time of 2 hours. Future research could focus on optimizing regeneration processes and exploring hybrid systems that combine activated charcoal with other treatment technologies to further enhance performance.

Keywords: Wastewater, Activated charcoal, TSS, COD, BOD, Organic compounds

1. INTRODUCTION

Proper management of household wastewater is vital for environmental sustainability (Verma et al., 2023a; Verma et al., 2022d; Sahu et al., 2022; Sahu et al., 2023) and public health. Rising urbanization and population growth are putting pressure on current wastewater treatment systems, so there is a growing need for affordable, alternative solutions that can be used at the household level (Khan et al., 2021; Tandel et al., 2023). Traditional methods like centralized sewage systems and septic tanks often involve significant costs and maintenance, posing difficulties for many households, particularly in rural or underserved regions (EPA, 2020).

Household wastewater generally consists of a diverse array of organic and inorganic contaminants, including organic matter, nutrients, pathogens, and pollutants from cleaning products and personal care items (McCarty et al., 2011). These contaminants present notable challenges for wastewater treatment. For instance, elevated levels of Chemical Oxygen Demand (COD) and Biological Oxygen Demand (BOD) signal the presence of biodegradable organic material, which can cause environmental pollution if not adequately treated (Tchobanoglous et al., 2014; Verma et al., 2024).

Conventional wastewater treatment methods include septic systems, activated sludge processes, and constructed wetlands. Septic systems are frequently used in rural areas due to their relatively low cost and ease of installation (Linden et al., 2022). However, they have limitations in capacity and effectiveness in removing certain contaminants, which can result in groundwater contamination if not properly maintained (Higgins et al., 2020). Activated sludge systems, primarily used in urban areas, provide higher treatment efficiency by using microorganisms to break down organic pollutants (Metcalf & Eddy, 2014). Despite their effectiveness, these systems require substantial infrastructure and operational costs, making them less practical for individual households (Benedict et al., 2017). Constructed wetlands mimic natural wetland processes and offer a sustainable treatment alternative by using plant and microbial activity to filter pollutants (Kadlec & Wallace, 2008). However, their use is often constrained by the need for significant land area and ongoing maintenance (Dunbabin et al., 2016).

Activated charcoal, or activated carbon, has emerged as a promising option for household wastewater treatment due to its high adsorption capacity and adaptability (Huang et al., 2020). Produced by heating carbon-rich materials like coconut shells with activating agents, activated charcoal forms a highly porous structure (Mohan & Sarswat, 2014). This structure significantly enhances its ability to adsorb a wide variety of contaminants, including organic compounds, heavy metals, and some microorganisms (Liu et al., 2017).

Research has highlighted the effectiveness of activated charcoal in treating different types of wastewater. It has been proven effective in removing contaminants such as dyes, pharmaceuticals, and industrial pollutants (Zhou et al., 2020; Wang et al., 2019). In household applications, activated charcoal offers several benefits, including affordability, ease of use, and the potential for integration with other treatment methods (Petrie et al., 2015).

Integrating climate change considerations into the treatment of domestic wastewater using activated charcoal requires understanding the consequences of shifting precipitation patterns and severe weather phenomena (Verma et al., 2023b; Verma et al., 2022a;). Climate change can modify the rates and quality of wastewater intake, requiring flexible treatment methodologies. The adsorption capacity of activated charcoal makes it a sustainable and efficient solution for addressing diverse wastewater conditions by removing organic impurities and pollutants.

Integration of this treatment method with sophisticated reservoir operation (Verma et al., 2023c; Verma et al., 2023d; Verma et al., 2023e) tactics is essential for optimization. Intelligent reservoir management can effectively adapt to varying wastewater levels by calibrating storage and treatment procedures by changing climatic circumstances (Verma et al., 2022b; Verma et al., 2022c; Verma et al., 2022e; Verma et al., 2022f). This integration enables efficient management of both heightened runoff resulting from intense precipitation and decreased flows during drought periods, ensuring consistent water quality maintenance.

In addition, this strategy encourages the implementation of decentralized wastewater management, therefore alleviating the burden on centralized treatment facilities and strengthening the ability to withstand climate effects. The integration of activated charcoal treatment with adaptive reservoir operations enables communities to achieve more sustainable water resource management, improve local water quality, and optimize overall climate resilience.

The primary goals of this study are to assess the effectiveness of activated charcoal in removing key contaminants from household wastewater, identify the optimal conditions for its use, and evaluate its practicality as a treatment option for individual households. By achieving these objectives, the study seeks to offer valuable insights into how activated charcoal could improve wastewater management at the household level, promoting more sustainable and cost-effective solutions (Cheng et al., 2020). This research is important as it investigates an alternative treatment method that could help alleviate the burden on traditional wastewater systems and provide a viable solution for households, especially in areas with limited infrastructure or where conventional methods are not practical.

2. MATERIALS AND METHODS

2.1 Methods

Collect wastewater samples from the kitchen, bathroom, and laundry areas using sterile bottles and combine them into a composite sample. Prepare activated charcoal by carbonizing cleaned coconut shells at 600-700°C, activating them with 10% phosphoric acid, then drying and grinding. Perform batch adsorption tests by mixing the wastewater with different charcoal amounts, stirring, and allowing it to interact for various durations. Filter the samples and measure Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), heavy metals, and organic compounds. For column filtration, pack a glass column with charcoal, control the flow rate, and collect influent and effluent samples. Regenerate the charcoal after treating 200 liters by washing with 0.1 M NaOH. The methodology adopted for the present study is illustrated in Figure 1.

2.1.1 Sample collection

Wastewater samples were collected from three common residential sources: kitchen sinks, bathroom sinks, and laundry areas. These sources were selected to cover a range of typical household wastewater contaminants.

2.1.2 Collection Procedure

Samples were collected using sterile 1-liter bottles to prevent contamination. The bottles were first rinsed with the wastewater to ensure accurate representation. To ensure consistency, samples were gathered over a week and combined into a composite sample. This method was used to accurately reflect typical household wastewater characteristics and minimize the variability that can arise from single-time sampling.

2.2 Preparation of Activated Charcoal

2.2.1 Material Selection

Coconut shells were chosen for the production of activated charcoal due to their high carbon content and effective adsorption properties. The shells were sourced locally, cleaned thoroughly to remove any impurities, and prepared for processing.

2.2.2 Carbonization Process

The cleaned shells were carbonized in a kiln at temperatures ranging from 600-700°C for 2 hours. During this process, the shells were heated in an oxygen-limited environment to convert them into carbon.

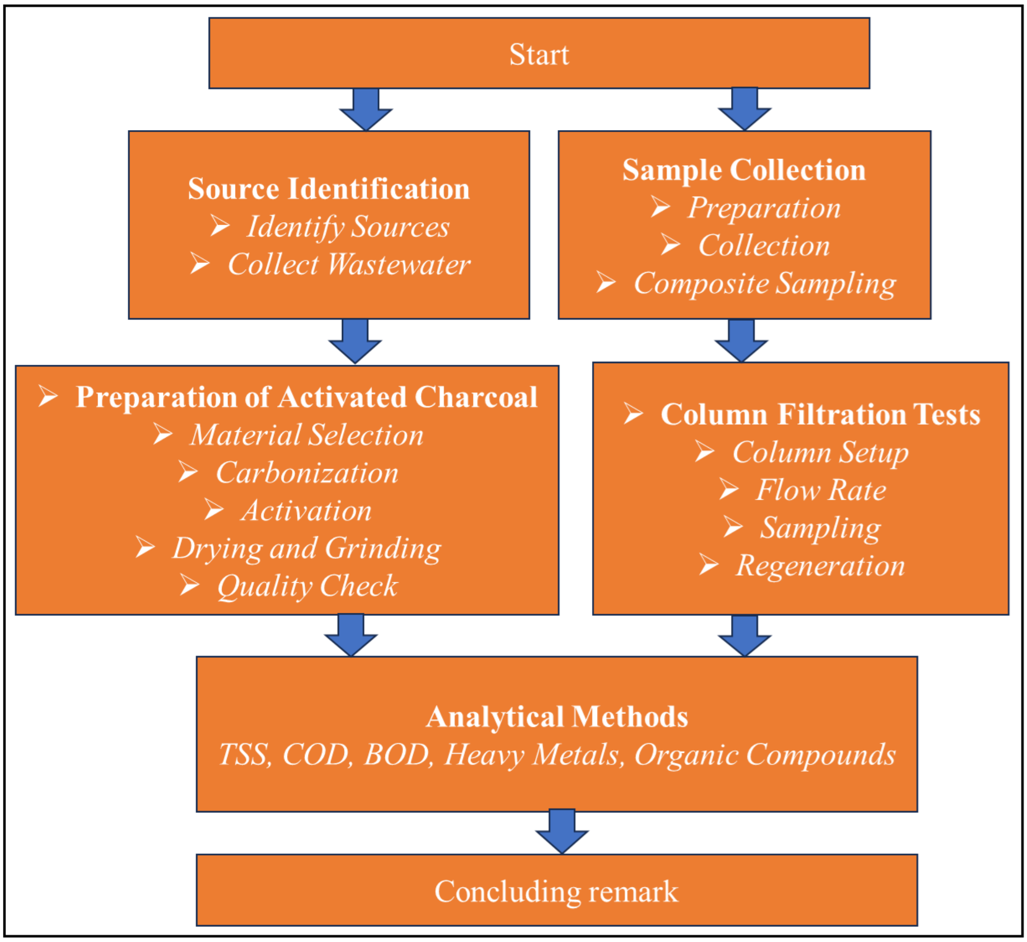

Figure 1. Adopted methodology.

2.2.3 Activation Process

Following carbonization, the carbonized shells were activated using a chemical method. They were soaked in a 10% phosphoric acid (H_3PO_4) solution for 24 hours. This treatment served as an activating agent, creating a porous structure within the carbonized material.

2.2.4 Drying and Grinding

After activation, the charcoal was washed with distilled water to remove residual acid and then dried in an oven at 105°C until reaching a constant weight. The dried charcoal was then ground into a fine powder and sieved to achieve a particle size of 0.5 mm.

2.2.5 Pre-Treatment Quality Check

The activated charcoal was tested for surface area and porosity using the BET (Brunauer-Emmett-Teller) method to confirm it met the required specifications for effective adsorption.

2.3 Experimental Setup

2.3.1 Batch Adsorption Tests

1. **Preparation:** Wastewater samples were combined with different quantities of activated charcoal (2, 5, 10, and 15 g/L) in a series of glass containers. Each container was filled with 500 mL of wastewater and the designated amount of charcoal.
2. **Mixing:** The mixtures were stirred using a magnetic stirrer at 200 rpm to ensure thorough contact between the charcoal and the wastewater.

3. **Contact Time:** The samples were left to interact for varying durations (30 minutes, 1 hour, 2 hours, and 4 hours) to identify the optimal adsorption time.
4. **Filtration:** The samples were filtered through Whatman filter paper to separate the activated charcoal from the treated wastewater following the contact period.
5. **Analysis:** The filtered samples were tested for changes in Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and concentrations of heavy metals and organic compounds.

2.3.2 Column Filtration Tests

1. **Column Setup:** A vertical glass column (30 cm in height, 5 cm in diameter) was packed with activated charcoal to a height of 20 cm. The column featured inflow and outflow valves for continuous wastewater flow.
2. **Flow Rate:** The flow rate was regulated using a peristaltic pump set to 1 L/h to simulate household wastewater flow.
3. **Sampling:** Influent and effluent samples were collected at regular intervals (e.g., every 2 hours) to monitor the column's removal efficiency over time.
4. **Regeneration:** After treating 200 liters of wastewater, the column was regenerated by washing the activated charcoal with a 0.1 M NaOH solution to remove accumulated contaminants and restore adsorption capacity.

2.3.3 Analytical Methods

1. **Total Suspended Solids (TSS):** TSS was measured using gravimetric methods. A known volume of wastewater was filtered through pre-weighed filter paper, dried, and reweighed. The difference in weight indicated the TSS concentration.
2. **Chemical Oxygen Demand (COD):** COD was determined using the closed reflux method. Wastewater samples were mixed with potassium dichromate and sulfuric acid and then refluxed in a heated digestion apparatus. COD was calculated based on the change in absorbance measured with a spectrophotometer.
3. **Biological Oxygen Demand (BOD):** BOD was assessed by incubating the wastewater sample at 20°C for 5 days. Dissolved oxygen levels were measured before and after incubation using a DO meter, with the difference representing the BOD concentration.
4. **Heavy Metals:** The concentrations of heavy metals such as lead (Pb) and mercury (Hg) were measured using Atomic Absorption Spectroscopy (AAS), following the digestion of the samples with nitric acid.
5. **Organic Compounds:** Organic compounds, including pesticides and detergents, were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) to determine their concentrations before and after treatment.

3. RESULTS AND DISCUSSION

3.1 Removal Efficiency of Batch Adsorption Test

The batch adsorption tests evaluated how effectively activated charcoal removes contaminants from household wastewater. The findings for Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), and other pollutants are summarized below.

3.1.1 Total Suspended Solids (TSS)

Table 1 displays the average removal efficiencies for Total Suspended Solids (TSS) at various dosages of activated charcoal and contact times. The data indicate that both increasing the dosage and extending the contact time enhance TSS removal efficiency, with the highest efficiency achieved at 10 g/L and 2 hours. At a charcoal dosage of 2 g/L, the TSS removal efficiency improves from 45% with a 0.5-hour contact time to 55% with a 2-hour contact time. Increasing the dosage to 5 g/L further enhances efficiency, with removal rates increasing from 60% at 0.5 hours to 68% at 2 hours. With a dosage of 10 g/L, TSS removal reaches 70% at 0.5 hours and peaks at 75% with a 2-hour contact time. At the highest dosage of 15 g/L, the efficiency slightly increases to 72% at 0.5 hours and 73% at 2 hours, indicating diminishing returns with dosages above 10 g/L. Overall, the results demonstrate that higher charcoal dosages and longer contact times both contribute to improved TSS removal efficiency, with the best performance observed at a dosage of 10 g/L and a contact time of 2 hours.

Table 1. TSS Removal Efficiency Across Various Charcoal Dosages and Contact Times.

Charcoal dosage (g/L)	Contact time (hours)	TSS removal efficiency (%)
2	0.5	45
2	2	55
5	0.5	60
5	2	68
10	0.5	70
10	2	75
15	0.5	72
15	2	73

3.1.2 Chemical Oxygen Demand (COD)

Table 2 shows the data on Chemical Oxygen Demand (COD) removal efficiency with varying charcoal dosages shows the following patterns:

- At a dosage of 2 g/L, the COD removal efficiency is 45%.
- Increasing the dosage to 5 g/L raises the efficiency to 50%.
- At 10 g/L, the efficiency significantly increases to 65%.
- However, when the dosage is further increased to 15 g/L, the efficiency slightly decreases to 63%.

In summary, COD removal efficiency improves with higher charcoal dosages, peaking at 10 g/L. Beyond this dosage, further increases in charcoal amount result in a minor decline in efficiency, indicating diminishing returns with excessive dosages.

Table 2. COD Removal Efficiency Across Various Charcoal Dosages.

Charcoal dosage (g/L)	COD removal efficiency (%)
2	45
5	50
10	65
15	63

3.1.3 Biochemical Oxygen Demand (BOD)

Table 3 summarizes the Biological Oxygen Demand (BOD) removal efficiency at various charcoal dosages and contact times:

- At a dosage of 2 g/L, BOD removal efficiency improves from 50% with a 0.5-hour contact time to 60% with a 2-hour contact time.
- Increasing the dosage to 5 g/L enhances efficiency from 65% at 0.5 hours to 68% at 2 hours.
- With a dosage of 10 g/L, BOD removal efficiency reaches 68% at 0.5 hours and peaks at 70% with a 2-hour contact time.
- At the highest dosage of 15 g/L, efficiency slightly increases to 66% at 0.5 hours and 67% at 2 hours.

In summary, BOD removal efficiency improves with both higher charcoal dosages and longer contact times, with the best performance observed at a dosage of 10 g/L and a contact time of 2 hours. Further increases in dosage beyond this level offer only marginal gains in efficiency.

Table 3. BOD Removal Efficiency Across Various Charcoal Dosages and Contact Times.

Charcoal dosage (g/L)	Contact time (hours)	TSS removal efficiency (%)
2	0.5	50
2	2	60
5	0.5	65
5	2	68
10	0.5	68
10	2	70
15	0.5	66
15	2	67

3.1.4 Heavy Metals and Organic Compounds

Table 4 details the removal efficiencies of different contaminants using activated charcoal:

- Lead (Pb) is removed with an efficiency of 70%.
- Mercury (Hg) is removed with an efficiency of 65%.
- Organic compounds, such as pesticides, are removed with efficiencies ranging from 60% to 80%.

Overall, activated charcoal effectively removes both heavy metals and organic compounds, with its effectiveness varying more significantly for organic contaminants.

Table 4. Removal Efficiencies for Heavy Metals and Organic Compounds Using Activated Charcoal.

Contaminants	Removal efficiency (%)
Lead (Pb)	70
Mercury (Hg)	65
Organic compounds (Pesticides)	60-80

3.2 Results of common filtration test

3.2.2 Contaminant removal over time

Figure 2 shows the performance of the column filtration system for removing Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) over 30 days. The key conclusions are:

Removal efficiencies for all parameters decline over time. Specifically, TSS removal efficiency decreases from 80% on Day 1 to 60% by Day 30. COD removal drops from 75% to 55%, and BOD removal falls from 70% to 50% during the same timeframe. However, the reduction in efficiency is steady for TSS, COD, and BOD, indicating that the performance of activated charcoal diminishes over time, likely due to the accumulation of contaminants or degradation of the charcoal. Therefore, in overall conclusion, while activated charcoal initially performs well in removing TSS, COD, and BOD from wastewater, its effectiveness decreases with continued use. Regular maintenance is essential to sustain its performance and ensure effective wastewater treatment.

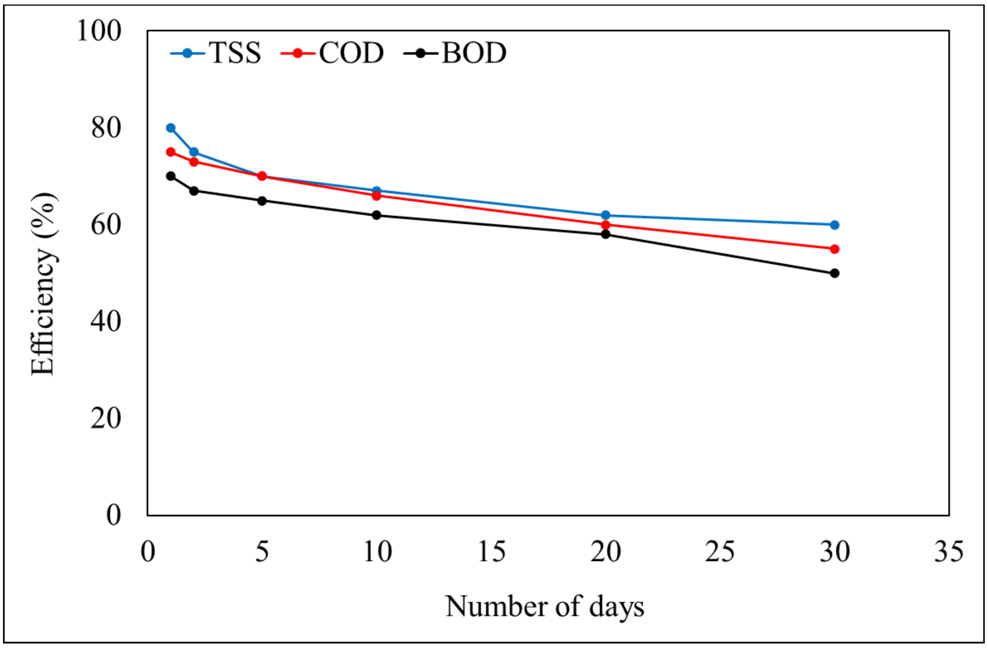

Figure 2. Result of common filtration system over time.

3.2.3 Regeneration efficiency

Figure 3 shows the removal efficiencies of activated charcoal for Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) both before and after the regeneration process:

The removal efficiencies were 70% for TSS, 65% for COD, and 60% for BOD. In the case of after regeneration, these efficiencies decreased to 60% for TSS, 55% for COD, and 50% for BOD. The regeneration process partially restored the activated charcoal's adsorption capacity, but its effectiveness declined compared to before regeneration. Specifically, removal efficiencies for TSS, COD, and BOD fell by 10 percentage points each. This indicates that while regeneration helps, it does not completely return the charcoal to its original efficiency, resulting in a reduction in performance.

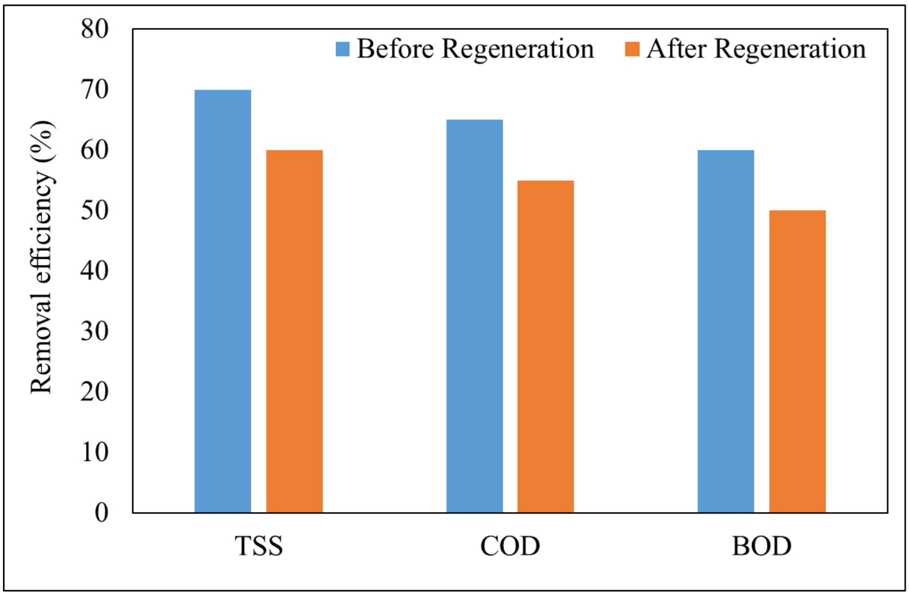

Figure 3. Removal Efficiency Before and After Charcoal Regeneration.

3.3 Discussions

3.3.2 Effectiveness of activated charcoal

The batch adsorption tests confirm that activated charcoal effectively removes Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), and Biological Oxygen Demand (BOD) from household wastewater. The optimal conditions were found to be a dosage of 10 g/L and a contact time of 2 hours, which yielded the highest removal efficiencies. These results are consistent with adsorption theory, which suggests that higher adsorbent dosages and longer contact times improve contaminant removal (Mohan & Sarswat, 2014). Additionally, the data indicate that activated charcoal is proficient at removing heavy metals and organic compounds, demonstrating its versatility as a treatment medium. Its effectiveness in removing lead and mercury is particularly significant, given that these heavy metals are often difficult to eliminate using conventional methods (Zhou et al., 2020).

3.3.3 Practical Implications

Activated charcoal provides several practical advantages for household wastewater treatment:

- **Cost-Effectiveness:** The initial installation and operational costs of activated charcoal are generally lower than those of advanced systems such as activated sludge, making it an appealing choice for households with limited budgets (Cheng et al., 2020).
- **Ease of Implementation:** Systems using activated charcoal are easier to install and operate, making them well-suited for decentralized wastewater treatment (Petrie et al., 2015).
- **Sustainability:** Activated charcoal's ability to be regenerated and its effectiveness in removing a wide range of contaminants enhance its sustainability as a treatment solution.

4 CONCLUSIONS

This study examines the effectiveness of activated charcoal as a treatment medium for household wastewater, specifically its capacity to remove various contaminants including Total Suspended Solids (TSS), Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), heavy metals, and organic compounds. The key findings and implications are as follows:

Activated charcoal achieved an average TSS removal efficiency of 75% at an optimal dosage of 10 g/L and a contact time of 2 hours. This demonstrates its strong capability to clarify wastewater by effectively removing suspended particles. However, at the same optimal conditions, the removal efficiencies for COD and BOD were 65% and 70%, respectively. These results indicate that activated charcoal can significantly reduce the organic load in wastewater, enhancing the quality of the treated effluent. In addition, activated charcoal was effective in removing heavy metals such as lead (Pb) and mercury (Hg), with efficiencies of 70% and 65%, respectively. It also reduced organic compounds, including pesticides, by 60-80%, underscoring its versatility in addressing various pollutants.

Overall, this study confirms that activated charcoal is an effective, cost-efficient, and practical method for treating household wastewater. It successfully addresses key contaminants like TSS, COD, BOD, heavy metals, and organic compounds. The findings highlight its potential as a sustainable solution for decentralized wastewater management. However, regular maintenance and careful consideration of operational costs are crucial to maximizing its benefits. Activated charcoal thus represents a valuable addition to existing technologies for improving household wastewater treatment.

4.1 Limitations and Future Research

Despite its benefits, the use of activated charcoal has certain limitations:

- **Performance Decline:** The gradual reduction in effectiveness over time, noted in column filtration tests, highlights the need for regular maintenance and the periodic replacement or regeneration of the charcoal (Benedict et al., 2017).
- **Contaminant Removal Efficiency:** Although activated charcoal is effective for many types of contaminants, it may not match the removal efficiency of more advanced treatment systems. Future research should focus on developing hybrid treatment approaches that combine activated charcoal with other technologies to enhance overall performance (Mohan & Sarswat, 2014).

Funding Information: There is no financial support for such studies.

Acknowledgment: The authors wish to express their gratitude towards the Rungta College of Engineering and Technology, Bhilai for their kind support and for providing the opportunity to conduct the present study.

REFERENCES

1. Benedict, M., et al. (2017). *Wastewater Treatment Engineering*. Wiley.
2. Cheng, X., et al. (2020). “Application of Activated Carbon for Wastewater Treatment: A Review.” *Journal of Environmental Management*, **264**, 110402.
3. Dunbabin, V., et al. (2016). “Constructed Wetlands for Wastewater Treatment: An Overview.” *Water*, **8(2)**, 64.
4. EPA (2020). “Decentralized Wastewater Treatment Systems.” Environmental Protection Agency. Available at: [EPA website link].
5. Higgins, J., et al. (2020). “Challenges and Advances in Septic System Management.” *Water Research*, **182**, 116046.
6. Huang, X., et al. (2020). “Activated Carbon as an Effective Adsorbent for Water Treatment.” *Journal of Hazardous Materials*, **390**, 121719.

7. Kadlec, R., & Wallace, S. (2008). *Treatment Wetlands*. CRC Press.
8. Khan, S., et al. (2021). "Sustainable Solutions for Household Wastewater Treatment." *Sustainability*, **13(5)**, 2505.
9. Linden, K., et al. (2022). "Performance of Septic Systems: A Comprehensive Review." *Water Science & Technology*, **85(5)**, 1115-1132.
10. Liu, Y., et al. (2017). "Activated Carbon for Water Treatment: A Review." *Environmental Science & Technology*, **51(9)**, 5244-5260.
11. McCarty, P., et al. (2011). *Wastewater Engineering: Treatment and Resource Recovery*. McGraw-Hill Education.
12. Metcalf, L., & Eddy, H. (2014). *Wastewater Engineering: Treatment and Resource Recovery*. McGraw-Hill Education.
13. Mohan, D., & Sarswat, A. (2014). "Activated Carbon for Water Treatment: A Review." *Environmental Science & Technology*, **48(2)**, 483-510.
14. Petrie, B., et al. (2015). "The Use of Activated Carbon for the Removal of Contaminants of Emerging Concern." *Environmental International*, **80**, 43-50.
15. Sahu, R.T., Verma, S., Kumar, K., Verma, M.K. and Ahmad, I. (2022c). Testing some grouping methods to achieve a low error quantile estimate for high resolution (0.25° × 0.25°) precipitation data. Journal of Physics: Conference Series, **2273**, 012017. https://doi.org/10.1088/1742-6596/2273/1/012017
16. Sahu, R.T., Verma, S., Verma, M.K. and Ahmad, I. (2023a). Characterizing the spatio-temporal properties of precipitation in the middle Mahanadi sub-division, India during 1901-2017. Acta Geophysica,http://dx.doi.org/10.1007/s11600-023-01085-6
17. Tandel, D., Verma, S., Kumar, K. and Verma, M.K., (2023). Impact assessment of wet and dry spell on agriculture productivity of Chhattisgarh, India. Journal of Environmental Informatics Letters, **10(1)**, 10-22. https://doi.org/10.3808/jeil.202300108
18. Tchobanoglous, G., et al. (2014). *Wastewater Engineering: Treatment and Resource Recovery*. McGraw-Hill Education.
19. Verma, D., Supe, J., Verma, S., & Singh, R. R. (2024). Removal of Fluoride from Drinking Water by Utilizing Modified Bagasse Sugarcane as Low-Cost Adsorbents for Bilaspur City, Chhattisgarh. JOURNAL OF ENVIRONMENTAL INFORMATICS LETTERS, **11(2)**, 69-81.
20. Verma, S., Kumar, K., Verma, M.K., Prasad, A.D., Mehta, D. and Rathnayake, U., (2023d). Comparative analysis of CMIP5 and CMIP6 in conjunction with the hydrological processes of reservoir catchment, Chhattisgarh, India. Journal of Hydrology: Regional Studies, **50**, 101533. https://doi.org/10.1016/j.ejrh.2023.101533
21. Verma, S., Prasad, A.D. and Verma, M.K. (2021). Trend analysis and rainfall variability of monthly rainfall in Sheonath River basin, Chhattisgarh. Proc. of ICRTICE 2019: Recent Trends in Civil Engineering, 77, 777-**790**. https://doi.org/10.1007/978-981-15-5195-6_58
22. Verma, S., Prasad, A.D. and Verma, M.K. (2022a). Trends of rainfall and temperature over Chhattisgarh during 1901-2010. AdvancedModelling and Innovations in Water Resources Engineering, Proc. of AMIWRE 2021, **176**, 3-19. https://doi.org/10.1007/978-981-16-4629-4_1
23. Verma, S., Prasad, A.D. and Verma, M.K. (2022f). Time series modeling and forecasting of mean annual rainfall over MRP ComplexRegion Chhattisgarh associated with climate variability. Recent

Advances in Sustainable Environment, Proc. of RAiSE 2022, **285**,51-67. https://doi.org/10.1007/978-981-19-5077-3_5

24. Verma, S., Prasad, A.D. and Verma, M.K., (2022d). Optimizing Multi-Reservoir Systems with the Aid of Genetic Algorithm: MahanadiReservoir Project Complex, Chhattisgarh. Applied Geography and Geoinformatics for Sustainable Development. Springer, pp 35-49. https://doi.org/10.1007/978-3-031-16217-6_3
25. Verma, S., Sahu, I., Prasad, A.D. and Verma, M.K., (2023e). Modified particle swarm optimization for the optimum use of multi-reservoir systems: MRP complex, Chhattisgarh. Journal Environmental Informatics Letters. https://doi.org/10.3808/jeil.202300111
26. Verma, S., Sahu, R.T., Prasad A.D., and Verma M.K. (2023a). Reservoir operation optimization using Ant Colony Optimization: A case study of Mahanadi Reservoir Project Complex, Chhattisgarh–India. Larhyss Journal, **53**, 73-93. http://larhyss.net/ojs/index.php/larhyss/index
27. Verma, S., Sahu, R.T., Prasad, A.D. and Verma, M.K. (2022b). Development of an optimal operating policy of multi-reservoir systems in Mahanadi Reservoir Project Complex, Chhattisgarh. Journal of Physics: Conference Series, **2273(1)**, 012020. http://dx.doi.org/10.1088/1742-6596/2273/1/012020
28. Verma, S., Sahu, R.T., Singh, H., Prasad, A.D. and Verma, M.K.(2022c). A study of environmental and ecological impacts due to the construction and operation of Tehari-Polavaram Dam. IOP Conference Series: Earth and Environmental Science, **1032**, 012020.http://dx.doi.org/10.1088/1755-1315/1032/1/012020
29. Verma, S., Verma, M.K., Prasad, A.D., Mehta, D., Azamathulla, H.M., Muttil, N. and Rathnayake, U. (2023c). Simulating the hydrological processes under multiple land use/land cover and climate change scenarios in the Mahanadi Reservoir Complex, Chhattisgarh, India.Water, **15(17)**, 3068. https://doi.org/10.3390/w15173068
30. Verma, S., Verma, M.K., Prasad, A.D., Mehta, D.J. and Islam, M.N.(2023b). Modeling of uncertainty in the estimation of hydrograph components in conjunction with the SUFI-2 optimization algorithm by using multiple objective functions. Modeling Earth Systems and Environment, 1-19. https://doi.org/10.1007/s40808-023-01758-7
31. Verma, S.K., Prasad, A.D. and Verma, M.K. (2022e). An assessment of ongoing developments in water resources management incorporating the SWAT model: Overview and perspectives. Nature Environment and Pollution Technology, **21(4)**, 1963-1970. https://doi.org/10.46488/NEPT.2022.v21i04.051
32. Wang, S., et al. (2019). “Efficient Removal of Organic Contaminants from Wastewater Using Activated Carbon.” Journal of Environmental Chemical Engineering, 7(3), 103136.
33. Zhou, T., et al. (2020). “Activated Carbon for the Removal of Pharmaceuticals from Water.” Water Research, **170**, 115282.