Effectiveness of Natural Adsorbents for Dye Removal in Waste Water: A Comparative Study

Deva Sadanand[1], Mehza S[2], Sruthi S Kumar[3] , Cinaya Tony[4]

[1]*UG Scholar, Department of Civil Engineering & Sree Buddha College of Engineering*
[2]*UG Scholar, Department of Civil Engineering & Sree Buddha College of Engineering*
[3]*UG Scholar, Department of Civil Engineering & Sree Buddha College of Engineering*
[4]*Asst.Professor, Department of Civil Engineering & Sree Buddha College of Engineering*

Abstract - Water is vital for life, plays a crucial role in the ecosystem, and is highly sought after due to its limited availability. The waste water from dye industries poses significant environmental challenges due to the presence of high concentrations of synthetic dyes and chemicals, which can adversely affect aquatic ecosystems and human health. This project investigates the effectiveness of three adsorbents, such as the banana trunk powder, biochar and rice husk ash, for removing dyes from waste water. The selection of these adsorbents was based on their affordability, accessibility and possible adsorption abilities. The efficiency of these adsorbents is evaluated via their adsorption onto activated carbon, which is produced through the chemical activation of these adsorbents in a hot air oven. Tests for pH, turbidity and hardness were used to assess the purity of the treated water. The study aims to evaluate how effectively three adsorbents, banana trunk powder, biochar, and rice husk ash, remove dyes and to identify the most efficient adsorbent for achieving optimal performance.

***Key Words*:** Adsorption, Hot Air Oven, Banana Trunk Powder, Biochar, Rice Husk Ash, Dyes

1.INTRODUCTION

Water is a vital resource that supports human life as well as ecosystems. Nevertheless, the increasing demand and growing scarcity of water in most regions have made its management a crucial issue worldwide. Industrial activities, especially those from the textile and dyeing industries, are significant sources of water pollution. The wastewater from these industries usually contains high concentration of dyes, and other toxic substances. When discharged into natural water bodies, such wastewater can severely degrade water quality, posing significant risks to aquatic life, ecosystems, and human health. A promising method for treating dye-contaminated wastewater is adsorption, where contaminants like dyes attach to the surface of solid materials. Activated carbon is commonly used because of its large surface area and strong adsorption ability. However, making activated carbon is costly and harmful to the environment, which calls for research into cheaper and more eco-friendly alternatives. There is great feasibility in using agricultural by-products, which are inexpensive, abundant, and biodegradable, for the removal of dye from waste water. This study looks at three adsorbents that can remove dyes from water: banana trunk powder, biochar, and rice husk ash. These have been chosen based on low costs, availability, and a potential for removing dye from water. To enhance the adsorption capacity of these materials, they are chemically activated in a hot air oven. Chemical activation involves treating the adsorbents with orthophosphoric acid, which open up additional pores and increase surface area, thus improving their effectiveness in dye removal. Tests for pH, turbidity and hardness were used to assess the purity of the treated water. The study aims to evaluate how effectively three adsorbents, banana trunk powder, biochar, and rice husk ash, remove dyes and to identify the most efficient adsorbent for achieving optimal performance.

2. Review of Literature

Based on the literature review, the majority of the studies have concentrated on the application of sustainable and low-cost adsorbent materials for the removal of dye from wastewater. Some of the papers covered biochar, agricultural by-product derived activated carbon, for instance, rice husk, and adsorbents produced from organic waste such as banana trunk powder, which are excellent candidate materials to use in treating wastewater. They have shown much promise in terms of being excellent at adsorbing toxic contaminants like reactive dyes because of their high surface area, porosity, and modification capabilities depending on the applications intended. The studies show that surface modification and utilization of agricultural waste products can make these adsorbents more efficient, not just effective but also cost-effective and eco-friendly.

3. Materials

The materials used in the present investigation are Biochar, Banana trunk, Rice husk ash (Adsorbents), dye waste water (synthetic dye), 98% H_3PO_4 (Orthophosphoric acid)) (Chemicals). The apparatus used are Hot air oven.

4. Methodology

The methodology followed in the present investigation has been given in the form of flow chart (Fig -1). In this study, the dye waste water used is synthetic dye, collected from a dyeing unit situated in Alappuzha district, India.

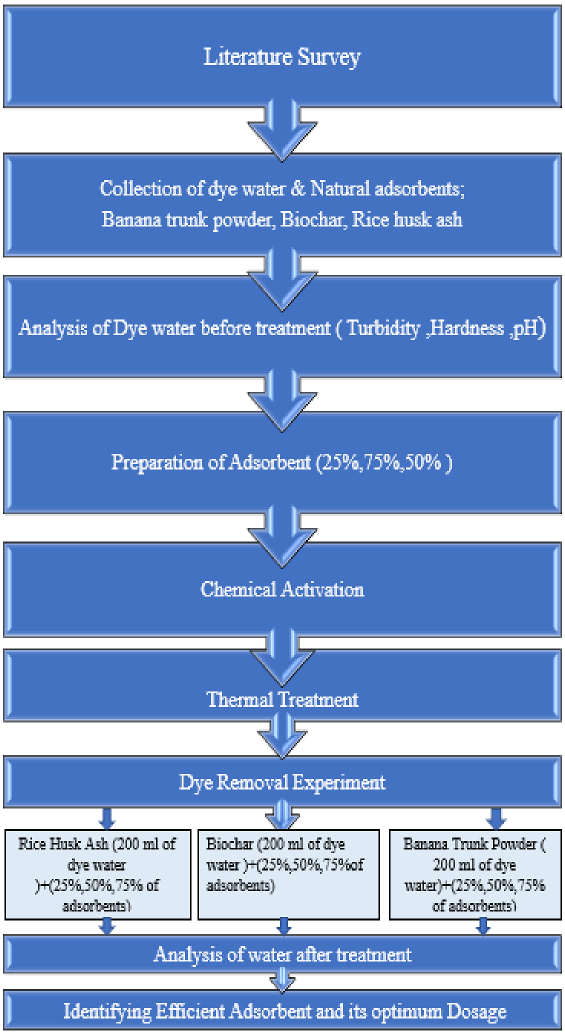

Fig -1: Methodology Flow Chart

5. Dye Removal Experiment

The adsorbent materials employed in this research are banana trunk powder, biochar, and rice husk ash, which were all gathered and sieved using a 150 µm mesh. The adsorption process started with the activation of these materials by heating them in a hot air oven. After this, chemical activation was done by exposing the materials to orthophosphoric acid and subjecting them to the hot air oven at 150°C for 3 hours. The activated adsorbents prepared were then added to the dye-polluted water. The solution was stirred and left undisturbed for 2 hours to facilitate adsorption. Subsequently, the solution was filtered and water quality tests performed to determine the efficacy of the dye removal process.

6. Results and Discussion

In the present study 50, 100 & 150 grams of activated carbon were added to 200 ml of dye-polluted wastewater. The test parameters studied throughout the research are pH, turbidity, and hardness. The raw water properties, both untreated and treated, are shown in Table 1,Table 2 and Table 3 respectively. These data were assessed to validate the efficiencies of applying alternative adsorbents such as banana trunk powder, biochar, and rice husk ash in treating the same water sample. The effects of these natural adsorbents on the quality of water were quantified and compared to evaluate their capacities for dye removal.

Table -1: Properties of the collected water before and after treatment (50 gram (25%) of adsorbents + 200 ml of dye wastewater)

Parameters	Initial Value	Biochar	Banana Trunk Powder	Rice Husk Ash	Standard Limit
pH	4.78	7.5	7.9	9	7-8
Turbidity	48 NTU	19 NTU	20 NTU	28 NTU	< 5
Hardness	1378.13 mg/l	465 mg/l	480.5 mg/l	496 mg/l	200 mg/l

Table -2: Properties of the collected water before and after treatment (100 gram (50%) of adsorbents + 200 ml of dye wastewater)

Parameters	Initial Value	Biochar	Banana Trunk Powder	Rice Husk Ash	Standard Limit
pH	4.78	7.3	7.6	9.3	7-8
Turbidity	48 NTU	14 NTU	19 NTU	25 NTU	< 5
Hardness	1378.13 mg/l	60.5 mg/l	655.22 mg/l	840 mg/l	200 mg/l

Table -3: Properties of the collected water before and after treatment (150 gram (75%) of adsorbents + 200 ml of dye wastewater)

Parameters	Initial Value	Biochar	Banana Trunk Powder	Rice Husk Ash	Standard Limit
pH	4.78	7.5	9	9	7-8
Turbidity	48 NTU	5 NTU	14 NTU	20 NTU	< 5
Hardness	1378.13 mg/l	72 mg/l	312.5 mg/l	722 mg/l	200 mg/l

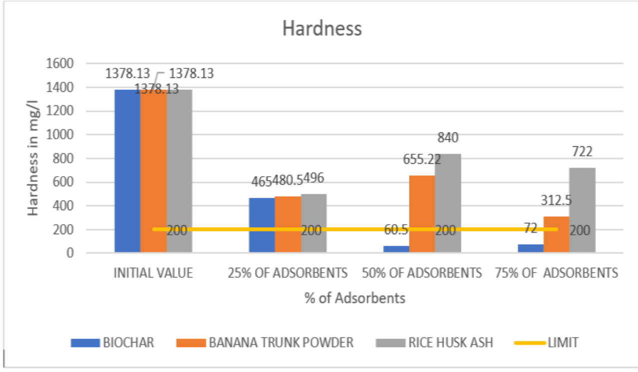

Fig -2: Effect of Different Adsorbents on Water Hardness Reduction

The figure 2 represents the lowering of water hardness following treatment with various adsorbents-biochar, banana trunk powder, and rice husk ash—at different dosages. Biochar has the greatest reduction in hardness, especially at higher percentages of adsorbents, while rice husk ash has the lowest reduction. The yellow limit line at 200 mg/l represents that only 50% and 75% dosages of biochar effectively lower hardness to the desired level.

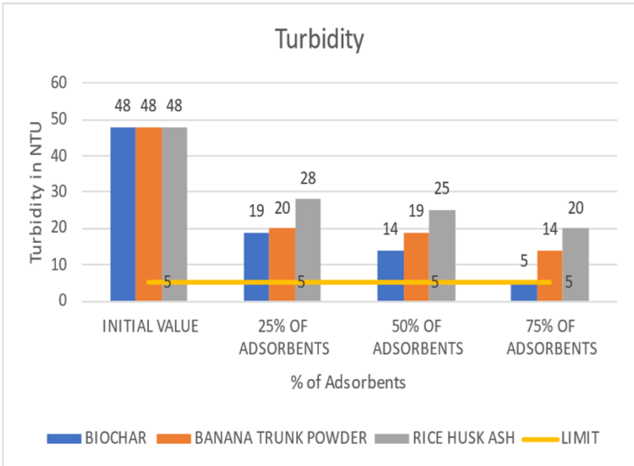

Fig -3: Effect of Different Adsorbents on Turbidity of Water

The figure 3 shows the reduction in turbidity after treatment with biochar, banana trunk powder, and rice husk ash at different dosages. Biochar is the most effective adsorbent, achieving the lowest turbidity levels, especially at 75% dosage, while rice husk ash shows the least reduction. The yellow limit line at 5 NTU indicates that only biochar at the highest dosage successfully brings turbidity within the acceptable range.

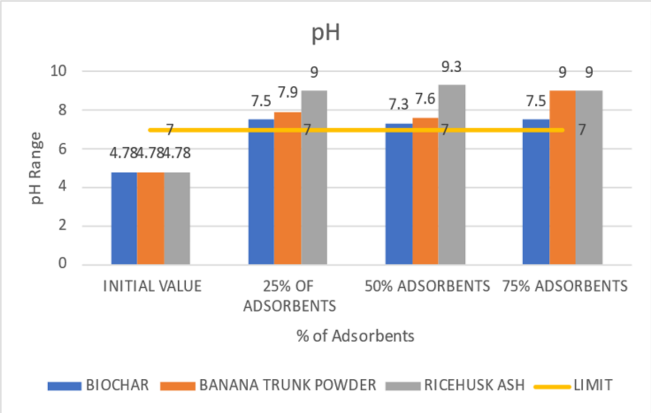

Fig -4: Effect of Different Adsorbents on pH levels

The figure 4 demonstrates the impact of different adsorbents on pH levels, showing an increase from the initial acidic value of 4.78 to more neutral or alkaline levels. While biochar and banana trunk powder bring the pH closer to the neutral limit of 7, rice husk ash raises it significantly, reaching up to 9. This suggests that biochar and banana trunk powder are more suitable for balancing pH within the acceptable range, whereas rice husk ash may lead to excessive alkalinity.

7. CONCLUSIONS

The research illustrates the possibility of three low-cost, natural adsorbents namely banana trunk powder, biochar, and rice husk ash in the removal of dyes from wastewater. The experimental results show that all three adsorbents can effectively enhance water quality with considerable pH, turbidity, and hardness reductions following treatment. Out of the three, biochar was the most efficient, with the best performance in pH and turbidity removal, followed by banana trunk powder and rice husk ash. The mechanism of orthophosphoric acid chemical activation also improved the adsorptive capacity of these materials further by opening up more pores and enlarging surface area, thereby leading to better dye removal. Biochar is the best adsorbent to enhance water quality because it effectively softens hardness, removes turbidity, and adjusts pH within reasonable ranges. In the removal of hardness, biochar brings down the concentration level from 1378.13 mg/L to 60.5 mg/L for 50% dosing, while rice husk ash is still at a high level of 722 mg/L at 75% dosing. Likewise, bio- char performs the maximum turbidity removal, reducing it from 48 NTU to 5 NTU at 75% dosage, while rice husk ash is still 20 NTU. Based on pH adjustment, biochar and banana trunk powder reduce the initial acidic pH of 4.78 to a point near the neutral capacity of 7, while rice husk ash increases it to 9, rendering the water too alkaline. Whereas banana trunk powder and rice husk ash are effective in purifying water, they tend to be above standard limits and therefore less ideal. Biochar also shows best results in the removal of dye from wastewater when 75% concentration of adsorbent is utilized in 200 mL of water. In conclusion, biochar is the best and most reliable means of treating water. From the results obtained, it can be observed that these agricultural wastes can be used as good, environmentally friendly alternatives to activated carbon in wastewater treatment, bearing environmental and cost advantages. In summary, application of natural adsorbents such as banana trunk powder, biochar, and rice husk ash was tremendous potential for sustainable wastewater treatment. Future studies can aim at optimizing the activation process and applying these adsorbents to other categories of wastewater for increased environmental benefit.

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BIOGRAPHY

The author 1, Deva Sadanand is currently a final-year undergraduate student pursuing a Bachelor's degree in Civil Engineering at Sree Buddha College of Engineering, Pattoor. She has actively engaged in academic projects and technical paper presentations.This research paper reflects her commitment to developing engineering solutions for real-world challenges. She aspires to pursue higher studies and contribute meaningfully to the advancement of civil engineering.