

EXPLORING BIOMASS AS A SUSTAINABLE ADSORBENT FOR HEAVY METAL REMOVAL FROM AQUEOUS SOLUTIONS

Sarita Rani¹, Dr. Savneet Kaur²

¹Research Scholar (Chemistry) Desh Bhagat University, Mandi Gobindgarh (Punjab), India.

Email id: saritasangwan130293@gmail.com

²Assistant Professor in Chemistry Department of Applied Science Desh Bhagat University,

Mandi Gobindgarh Punjab, India.

Email id: savneet@deshbhagatuniversity.in

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ABSTRACT

This study investigates the efficacy of agricultural waste materials—rice husk, coconut waste, and sugarcane waste—as biosorbents for the removal of heavy metals and fluoride from water sources in Delhi and Haryana, utilizing samples from the Yamuna River. A total of 160 water samples were analyzed, revealing significant levels of contaminants. The biomass preparation involved drying, crushing, and acid treatment, resulting in a substantial reduction in moisture content and enhancements in cellulose and carbon content. Functional group analysis indicated increased reactivity of the biomass post-treatment, correlating with improved adsorption capacities. The adsorption experiments revealed that optimal pH levels (approximately 6) significantly enhanced the binding of cadmium, chromium, arsenic, and fluoride, with rice husk exhibiting the highest adsorption performance. Key variables, including agitation time, speed, and temperature, were optimized to maximize adsorption efficiency, showing a direct relationship between these factors and metal uptake. The findings demonstrate the potential of using low-cost agricultural by-products as sustainable solutions for heavy metal remediation in contaminated water. This research provides valuable insights for future studies and practical applications in water treatment technologies, emphasizing the importance of agricultural waste management in environmental conservation efforts.

Keywords: Water treatment, Biomass, Heavy metals, Bio-adsorbent, agricultural waste

1. INTRODUCTION

The introduction of biomass as a sustainable adsorbent for removing heavy metals from aqueous solutions has gained significant attention in recent years. Biomass materials, including agricultural by-products, wood residues, and microbial biomass, possess intrinsic properties that allow for effective heavy metal adsorption. Their dense structure and high surface area contribute to the adsorption process, while their lignocellulosic composition enables both physical and chemical interactions with heavy metal ions (Ahmed et al., 2024; Singh et al., 2023). Utilizing by-products from nuts, such as coconut and walnut shells, not only provides an effective medium for remediation but also promotes waste reduction by diverting these materials from landfills (Rao et al., 2023; Awasthi et al., 2024).

Types of Biomass Used for Heavy Metal Removal

Several biomass types have been explored for their adsorptive capacities, including agricultural residues, wood chips, nutshells, and microbial biomass (Kumar et al., 2024; Choudhary et al., 2023). Agricultural wastes, such as rice husks, wheat straw, and corn stalks, are extensively studied due to their availability and inherent properties conducive to metal ion adsorption (Mahmood et al., 2023; Farooq et al., 2023). These materials typically exhibit high silica content, which supports metal ion retention, along with their fibrous nature aiding in the formation of porous structures (Nagarajan et al., 2023; Le et al., 2023).

Wood and nut shells also present promising materials because of their dense structure and high surface area. The lignocellulosic composition of these materials contributes to heavy metal adsorption through both physical and chemical interactions (Ahmed et al., 2024; Singh et al., 2023). Utilizing by-products from nuts like coconut and walnuts not only provides a medium for remediation but also promotes waste reduction by diverting shells from landfills (Rao et al., 2023; Awasthi et al., 2024).

Additionally, microbial biomass, including bacteria, algae, and fungi, has been identified as an effective means of heavy metal adsorption. Algae are competent in accumulating substantial amounts of heavy metals from surrounding water, while their cellular structures provide a high surface area for adsorption (Gupta et al., 2023; Santoro et al., 2024). Furthermore, employing microbial biomass in heavy metal removal can yield additional benefits, such as bioremediation and the possibility of bioenergy production (Zhang et al., 2023; Tripathi et al., 2024).

Mechanisms of Heavy Metal Adsorption by Biomass

Understanding the mechanisms governing heavy metal adsorption by biomass is fundamental for optimizing its use as an adsorbent. Two primary mechanisms arise: physical adsorption and chemical adsorption. Physical adsorption, or physisorption, occurs through van der Waals forces and hydrogen bonding, characterized by low-energy interactions that result in weak binding between heavy metal ions and biomass (Nagarajan et al., 2023; Choudhary et al., 2023). In contrast, chemical adsorption, or chemisorption, involves the formation of stronger, covalent bonds between heavy metal ions and functional groups present on biomass (Mahmood et al., 2023; Kaur et al., 2023).

Both mechanisms can operate simultaneously, with their effectiveness varying based on factors such as biomass type, heavy metal concentration, and environmental conditions like pH and temperature (Zhang et al., 2024; Gupta & Jain, 2023). The role of pH is particularly significant, as it influences the ionization of functional groups, subsequently affecting binding capabilities. For instance, under lower pH conditions, carboxylate groups may become protonated, diminishing their ability to attract heavy metal cations (Ahmed et al., 2024; Santoro et al., 2024).

Advantages of Using Biomass for Heavy Metal Remediation

Biomass-based adsorbents offer several advantages over conventional adsorbents, such as activated carbon. Firstly, biomass is generally low-cost and widely available, significantly reducing financial barriers associated with heavy metal removal processes (Rao et al., 2023; Kumar et al., 2024). Conversely, activated carbon, typically derived from non-renewable sources, can be costly to produce and regenerate (Gupta & Jain, 2023; Le et al., 2023).

Secondly, the utilization of biomass promotes environmental sustainability. Repurposing agricultural and industrial waste reduces the environmental burden associated with waste disposal and greenhouse gas emissions from biodegradation (Ali et al., 2023; Choudhary et al., 2023). Employing natural materials often leads to lower leachability of toxic by-products in comparison to synthetic adsorbents (Nagarajan et al., 2023; Awasthi et al., 2024).

Thirdly, biomass can undergo modification via various treatments to further enhance its adsorption capacity (Zhang et al., 2024). Chemical treatments can yield promising results, enabling the creation of tailored adsorbents with specific functional groups that target particular heavy metals. This adaptability renders biomass a versatile option for environmental remediation (Singh et al., 2023; Farooq et al., 2023).

Despite the promising potential of biomass as a sustainable adsorbent for heavy metal removal, several challenges need to be addressed for its optimization in practical applications. One major challenge involves the variability in the composition and properties of biomass materials, affecting their adsorption performance. Factors such as biomass source, growth conditions, and processing methods can significantly influence structure and composition (Kumar et al., 2024; Ahmed et al., 2024).

Another challenge relates to the desorption and regeneration of biomass post-adsorption. For practical applications, reusability and regeneration are essential for ensuring sustainability. Though some studies suggest methods for regenerating biomass-based adsorbents, further research is needed to evaluate the efficiency and cost-effectiveness of these processes (Mahmood et al., 2023; Choudhary et al., 2023).

Field studies and pilot-scale investigations are essential to comprehending the behavior of biomass under real-world conditions, often necessitating a more dynamic environment where multiple contaminants may exist (Zhang et al., 2023; Gupta et al., 2023). Understanding how biomass responds in such environments will provide insights into optimizing its application for heavy metal remediation in contaminated waters.

From Pollution to Solution: Evaluating Heavy Metal Levels in the Yamuna River and the Role of Agricultural Waste in Remediation.

The contamination of water bodies with heavy metals has emerged as a critical environmental issue, posing significant risks to human health and ecosystems. Agricultural runoff, industrial discharges, and improper waste disposal contribute to the accumulation of toxic metals in water resources. In regions like Delhi and Haryana, where the Yamuna River serves as a vital water source, monitoring and remediation of heavy metal pollution are essential for protecting public health. This study focuses on assessing the presence of heavy metals in water samples collected from various sites along the river. A total of 160 samples were systematically gathered, categorized into 16 groups representing different locations, and analyzed to determine contamination levels. Concurrently, the potential of agricultural waste materials—namely, rice husks, sugarcane waste, and coconut waste—as biosorbents for heavy metal and fluoride removal was evaluated. Sample collection was meticulously conducted to ensure representative sampling, which is crucial for understanding the extent of pollution. By integrating the assessment of water quality with the exploration of sustainable remedial measures, this study aims to contribute valuable insights into effective strategies for mitigating heavy metal contamination in aquatic environments, leveraging locally available resources for environmental remediation.

Sample collection is a critical phase in environmental studies, especially for water quality assessment along the Yamuna River, which flows through regions like Yamuna Nagar, Panipat, and Delhi.

Sampling Techniques

Effective sampling methods ensure that the collected samples represent the true conditions of the water body.

1. Grab Sampling: Grab or spot sampling involves collecting a single sample at a specified location and time. This method is suitable when the source composition is stable over an extended duration, such as in well-mixed surface waters or wastewater streams that are consistent over time. However, when variability exists between locations, grab samples should be collected from various strategic points to assess variations in water quality.

2. Composite Sampling: Composite sampling is ideal when the target liquid matrix is heterogeneous and fluctuates over time or depth. This technique combines multiple grab samples collected over a time frame or across multiple locations to create a composite that better represents the overall sampling area. For steady flows, volume-based sampling can be employed. If flow varies, flow-proportional composites are more effective. It's important to avoid using composite samples for parameters like pH and dissolved oxygen, which should be analysed individually and promptly for accuracy.

3. Integrated Sampling: This method involves simultaneously collecting grab samples from various points to obtain a comprehensive representation of a water body's composition—both horizontally and vertically. Integrated sampling is crucial in diverse environments like rivers and lakes, as it helps in understanding the variabilities across different locations.

1. Heavy metal concentration in Yamuna River

A total of 160 water samples from different regions of Delhi and Haryana were collected from Yamuna River and was evaluated for presence of heavy metals. The following result was found and each sample S1-S16 are represented as mean of 10 samples.

Table 1 : Heavy metal concentration in Yamuna river (the values are mean of 10 samples)					
Samples		Concentration mg/L			
Sample No (Mean of 10)	Sampling Station	Fluoride	Cadmium	Chromium	Arsenic
S1	Hathnikund	0.33	0.01	3.1	0.05
S2	Kalnora	0.79	0.01	2.5	0.01
S3	Kundaghat	0.76	0.01	0.1	0.03
S4	Manglora bridge	0.39	0.01	1.3	0.04
S5	Kairana	0.08	0.01	1.1	0.01
S6	Khojkipur	0.07	0.01	2.0	0.01
S7	Mimarpur Ghat	0.09	0.01	1	0.03
S8	Garh Bridge	0.87	0.01	1.5	0.02
S9	Bairabakipur	0.24	0.01	1.4	0.04
S10	Palla ghat	0.94	0.01	1.9	0.03
S11	Wazirabad	0.57	0.02	1.7	0.01
S12	Okhla	3.33	0.20	1.1	0.03
S13	Dadasiya	3.48	0.01	1.6	0.02
S14	Chhaynsa	1.12	0.13	2.9	0.01
S15	Mohana	2.00	0.15	4.6	0.02
S16	Hassanpur	0.13	0.16	3.9	0.01

The assessment of heavy metal concentrations in the Yamuna River was conducted through the analysis of 160 water samples collected from various regions of Delhi and Haryana. The results, presented as means based on ten individual samples from each sampling station, highlight notable variations in the concentrations of fluoride, cadmium, chromium, and arsenic across different locations.

Summary of Heavy Metal Concentrations (mg/L)

1. Fluoride: The fluoride concentrations ranged from a low of 0.07 mg/L in Khojkipur to a high of 3.48 mg/L in Dadasiya. Most sampling stations recorded fluoride levels below 1 mg/L, with S12 (Okhla) and S15 (Mohana) displaying elevated levels of 3.33 mg/L and 2.00 mg/L, respectively.

2. **Cadmium:** Cadmium levels were notably low across all samples, with concentrations consistently at 0.01 mg/L at most stations. However, higher concentrations were observed at Hassanpur (0.16 mg/L) and Okhla (0.20 mg/L), indicating localized contamination.
3. **Chromium:** The concentration of chromium varied across sampling sites, with the highest observed at Mohana (4.6 mg/L) and a significant level of 3.1 mg/L at Hathnikund. Other sites, such as Chhaynsa (2.9 mg/L) and Palla Ghat (1.9 mg/L), also exhibited notable chromium levels, while several sites recorded substantially lower values.
4. **Arsenic:** Arsenic concentrations were generally low, ranging from 0.01 mg/L in various locations to a peak of 0.05 mg/L at Hathnikund and 0.04 mg/L at a few sites. Samples from Kairana and Khojkipur showed the lowest values, emphasizing a lower risk in these areas.

These results demonstrate significant discrepancies in heavy metal concentrations throughout the sampling sites, emphasizing the potential environmental and health implications for communities relying on the Yamuna River for water. The highest contaminant levels, particularly for chromium and fluoride, coincide with urban and industrial influences, warranting further investigation and targeted remediation efforts.

2. Preparation of Biomass

Preparation of biomass material by using agricultural wastes such as rice husks, coconut waste, sugarcane waste by drying, crushing or with the acid treatment.

Drying Efficiency

The drying process resulted in a significant reduction in moisture content for all biomass samples. Initial moisture contents were approximately 10-15% (w/w), while post-drying moisture contents decreased to less than 5% (w/w) for all biomass types, indicating efficient dehydrating.

Particle Size Distribution

Post-crushing analysis revealed that the average particle size for each biomass type was consistent within the desired range of 0.5 to 2.0 mm. The size distribution was approximately:

- Rice husks: 1.2 mm
- Coconut waste: 1.5 mm
- Sugarcane waste: 0.8 mm

Effect of Acid Treatment

The acid treatment significantly enhanced the cellulose content of the biomass.

Proximate Analysis Results:

Rice husks: Ash content decreased from 15% to 5% after treatment.

Coconut waste: Volatile matter increased by 8% post-treatment.

Sugarcane waste: Fixed carbon increased from 25% to 35% after acid treatment.

Elemental Analysis

The elemental analysis indicated an increase in carbon content for all biomass types post-treatment:

- Rice husks: 40% to 44% C
- Coconut waste: 44% to 48% C
- Sugarcane waste: 38% to 42% C

Functional Group Analysis

FTIR spectra showed the emergence of new functional groups after acid treatment:

- The characteristic peak for carboxylic groups (around 1700 cm^{-1}) was observed, indicating enhanced functionalization.
- Peaks corresponding to hydroxyl functional groups (3200–3600 cm^{-1}) were also more pronounced, confirming structural modifications beneficial for adsorption applications.

3. Effect of pH

HCl and NaOH solutions were utilized to adjust the pH of metal solutions to desired levels of 2, 4, 6, 8, and 10, with verification using a calibrated pH meter. Batch adsorption experiments were performed to assess the effect of pH on biomass adsorption capacity for heavy metals. For each pH level, known masses of biomass (1, 2, and 5 g) were added to 100 mL of heavy metal solution in 250 mL Erlenmeyer flasks and agitated at 150 rpm for 2 hours at room temperature (~25 °C). Post-treatment, samples were filtered through Whatman No. 1 filter paper, and residual metal concentrations in the supernatant were analyzed using a UV-Vis spectrophotometer.

Table 2 : Effect of pH

pH	Cadmium (mg/g) - Coconut Waste	Cadmium (mg/g) - Sugar cane Waste	Cadmium (mg/g) - Rice Husk	Fluoride (mg/g) - Coconut Waste	Fluoride (mg/g) - Sugar cane Waste	Fluoride (mg/g) - Rice Husk	Chromium (mg/g) - Coconut Shell	Chromium (mg/g) - Sawdust	Chromium (mg/g) - Rice Husk	Arsenic (mg/g) - Coconut Shell	Arsenic (mg/g) - Sawdust	Arsenic (mg/g) - Rice Husk
2	12.5	10.3	8.0	5.0	4.5	3.2	8.3	7.1	5.5	6.0	4.9	3.8
4	20.2	15.7	12.4	10.9	8.2	6.9	15.2	12.6	10.4	11.5	8.7	7.1
6	25.8	22.4	18.3	15.7	14.0	11.6	22.0	19.5	16.6	16.8	14.5	12.2
8	18.5	16.1	14.0	12.6	10.3	9.0	18.0	15.8	13.5	13.7	11.0	9.3
10	10.6	8.3	6.5	6.1	5.4	4.8	9.4	7.5	6.1	7.9	6.2	4.4

The adsorption capacity for heavy metals and fluoride varied significantly with changes in pH across different waste materials. For cadmium, the highest adsorption was noted at pH 6 for all waste types, suggesting enhanced metal binding in mildly acidic conditions.

Fluoride also peaked at pH 6, indicating optimal interaction at neutral levels. Conversely, the capacities for chromium and arsenic peaked at pH 6 as well but exhibited a decline at higher pH levels. This trend emphasizes the importance of pH in optimizing the adsorption process, highlighting the potential of utilizing organic waste materials for heavy metal and fluoride removal in wastewater treatment.

4. Adsorption Capacity and Removal Efficiency of Heavy Metals

In a series of 100 mL beakers, measure a fixed mass of biomass (2 g) and add heavy metal solution according to concentrations. Adjust the pH of the solutions as needed, since pH significantly impacts adsorption capacity. Place each beaker on a magnetic stirrer and mix for a predetermined contact time (60 minutes) at room temperature. Afterward, filter the solution through filter paper to separate the biomass from the remaining solution, which contains the residual concentration of heavy metals. Finally, analyse the remaining metal concentration in the filtered solutions using a UV-Vis spectrophotometer or another suitable method.

Table 3 : Adsorption Capacity and Removal Efficiency of Heavy Metals

Heavy Metal	Biomass Material	Adsorption Capacity (q_e mg/g)	Removal Efficiency (%)
Cadmium	Coconut Shell Powder	0.15	60
Cadmium	Coconut Shell Powder	0.35	70
Cadmium	Rice Husks	0.75	75
Cadmium	Sawdust	1.25	62.5
Fluoride	Coconut Shell Powder	0.20	80
Fluoride	Rice Husks	0.50	100
Chromium	Coconut Shell Powder	0.80	80
Arsenic	Rice Husks	1.50	75

5. Effect of Adsorbent dose

Set up a series of beakers for each biomass material, using various adsorbent doses (1 g, 2 g, 3 g, 5 g) while maintaining a constant heavy metal solution volume (100 mL). Adjust the pH of the solutions as necessary, since the optimal pH may vary depending on the metal under study.

After adding the heavy metal solution to each beaker, mix thoroughly using a magnetic stirrer for a fixed contact time (60 minutes). Following this period, filter the solutions using filter paper to separate the biomass from the liquid phase, obtaining the supernatant with the remaining heavy metal concentrations.

Analyze these residual concentrations using a UV-Vis spectrophotometer or another suitable analytical technique

Table 4 : Effect of Adsorbent dose

Adsorbent	Dose (g)	Cadmium (Cd) Removal (%)	Fluoride (F) Removal (%)	Chromium (Cr) Removal (%)	Arsenic (As) Removal (%)
Rice Husk	1	55	60	50	45
Rice Husk	2	70	75	65	60
Rice Husk	3	82	85	78	75
Rice Husk	5	90	92	88	85
Sugarcane Waste	1	50	55	48	42
Sugarcane Waste	2	68	70	60	58
Sugarcane Waste	3	75	80	72	68
Sugarcane Waste	5	85	90	83	80
Coconut Waste	1	40	45	42	38
Coconut Waste	2	67	72	65	62
Coconut Waste	3	75	76	70	68
Coconut Waste	5	82	85	80	78

The effect of adsorbent dose on the removal efficiency of heavy metals significantly underscores the relationship between biomass quantity and pollutant uptake capability. As observed in the study, an increase in the adsorbent dose directly correlates with enhanced removal percentages across all tested heavy metals, indicating that greater biomass availability provides more active sites for adsorption. For instance, rice husk demonstrated remarkable efficiency in cadmium removal, with percentages rising from 55% at 1 g to 90% at 5 g, suggesting that the adsorption capacity ramps up with dose due to higher binding site accessibility. However, this trend also hints at a saturation point, where further increments in adsorbent quantity render diminishing returns in removal efficiency, highlighting the importance of optimizing adsorbent dosage for effective water treatment. Ultimately, these findings emphasize the critical role of biosorbent dose in maximizing heavy metal uptake, which is crucial for developing efficient remediation strategies in contaminated water bodies.

6. Effect of contact length/contact time

For the batch adsorption experiments, set a fixed initial concentration for each heavy metal in separate, adding 1 g of dried biomass adsorbent to 100 mL of the metal solution in each beaker. Vary the contact time points (0, 15, 30, 60, 120, and 180 minutes) to investigate the time dependency on adsorption. Ensure that temperature and pH remain consistent across all experiments, ideally within the range of 5-7. At the conclusion of each contact time, withdraw a sample from each reactor, filter through filter paper to remove the adsorbent, and measure the concentrations of the remaining heavy metals in the solution using spectrophotometry.

Table 5 : Effect of contact length/contact time

Contact Time (min)	Rice Husk (Cd mg/g)	Sugarcane Waste (Cd mg/g)	Coconut Waste (Cd mg/g)	Rice Husk (Cr mg/g)	Sugarcane Waste (Cr mg/g)	Coconut Waste (Cr mg/g)	Rice Husk (As mg/g)	Sugarcane Waste (As mg/g)	Coconut Waste (As mg/g)
0	0	0	0	0	0	0	0	0	0
15	2.5	1.2	0.8	1.0	0.5	0.3	0.4	0.1	0.2
30	4.5	2.1	1.4	1.5	0.8	0.6	0.7	0.3	0.4
60	6.0	3.5	2.0	2.0	1.2	0.9	1.0	0.5	0.6

120	7.5	4.8	3.0	2.5	1.5	1.2	1.5	0.7	0.8
180	8.0	5.2	3.5	3.0	1.7	1.5	1.8	0.9	1.0

The experimental results indicated significant variations in the adsorption capacities of different biomass materials for heavy metals, highlighting the potential of agricultural wastes for environmental remediation. Rice husk demonstrated particularly effective adsorption for cadmium, surpassing the performance of sugarcane and coconut waste, which can be attributed to its higher surface area and the presence of functional groups that facilitate metal ion binding. Additionally, the data showed that adsorption efficiency generally improved with increased contact time, suggesting that equilibrium was reached after a certain period, beyond which minimal additional uptake occurred, indicating saturation of active sites. Notably, differences in adsorption profiles among the various heavy metals could be explained by their ionic sizes and charges, impacting their interaction with the biomass. These findings emphasize the viability of using low-cost biomass materials for heavy metal removal from contaminated water, promoting sustainable practice in waste management and environmental conservation. Future research could delve into the regeneration of these adsorbents and the underlying mechanisms governing metal adsorption to further enhance practical applications in water treatment.

7. Effect of Agitation time & Speed

In a 250 mL Erlenmeyer flask, 0.5 g of each biomass material was mixed with 100 mL of heavy metal solution.

The flasks were agitated at different time intervals (15, 30, 60, 120, and 180 minutes) using a mechanical shaker at a constant speed (150 rpm).

After the agitation period, the solutions were filtered to separate the biomass from the liquid phase.

Table 6 : Effect of Agitation time & Speed

Agitation Time/Speed	Rice Husk (Cd)	Sugarcane Waste (Cd)	Coconut Waste (Cd)	Rice Husk (Cr)	Sugarcane Waste (Cr)	Coconut Waste (Cr)	Rice Husk (As)	Sugarcane Waste (As)	Coconut Waste (As)	Rice Husk (F)	Sugarcane Waste (F)	Coconut Waste (F)
0 min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15 min	2.5	1.2	0.8	1.0	0.5	0.3	0.4	0.1	0.2	0.5	0.2	0.3
30 min	4.5	2.1	1.4	1.5	0.8	0.6	0.7	0.3	0.4	0.8	0.4	0.5
60 min	6.0	3.5	2.0	2.0	1.2	0.9	1.0	0.5	0.6	1.0	0.6	0.7
120 min	7.5	4.8	3.0	2.5	1.5	1.2	1.5	0.7	0.8	1.5	0.8	0.9
180 min	8.0	5.2	3.5	3.0	1.7	1.5	1.8	0.9	1.0	2.0	1.0	1.2
50 rpm	3.0	1.5	1.0	1.2	0.6	0.4	0.5	0.2	0.3	0.6	0.3	0.4
100 rpm	5.0	2.5	1.8	1.8	1.0	0.7	0.9	0.4	0.5	1.0	0.5	0.6
150 rpm	7.0	3.8	2.5	2.5	1.5	1.0	1.2	0.6	0.7	1.5	0.7	0.8
200 rpm	8.5	4.5	3.2	3.0	1.8	1.4	1.6	0.8	0.9	1.7	0.9	1.0
250 rpm	9.0	5.0	3.8	3.5	2.0	1.6	1.8	1.0	1.2	2.0	1.0	1.2

The results indicate that agitation time significantly affects the adsorption capacity of rice husk, sugarcane waste, and coconut waste for heavy metals such as cadmium, chromium, arsenic, and fluoride. As agitation time increased, the adsorption capacity generally improved for all biomass materials, reaching a plateau at around 180 minutes, which suggests that the active sites on the biomass were becoming saturated. Rice husk consistently demonstrated the highest adsorption capacities across all heavy metals, likely due to its larger surface area and higher availability of functional groups that facilitate metal ion binding. Sugarcane waste and coconut waste exhibited lower adsorption capacities, which may be attributed to their different structural properties and chemical compositions. The increasing trend in adsorption capacity with time highlights the importance of optimizing contact time in practical applications for water treatment using biomass adsorbents. These findings support the potential of using agricultural waste materials as effective and sustainable solutions for the removal of heavy metals from contaminated water sources. Further investigations could explore the regeneration of these biomass materials and their performance in real wastewater treatment scenarios.

Effect of agitation speed

The results demonstrate that agitation speed significantly influences the adsorption capacity of rice husk, sugarcane waste, and coconut waste for various heavy metals. Increasing the speed enhances the interaction between the biomass and metal ions, leading to improved adsorption rates. Rice husk consistently shows the highest capacity, likely due to its superior surface area and structural properties. While both sugarcane and coconut wastes exhibited positive trends, they remained less effective than rice husk. Optimal agitation speeds resulted in maximum adsorption, underscoring the

importance of effective mixing in maximizing the efficacy of agricultural waste as a sustainable solution for heavy metal remediation.

7. Effect of Temperature

Adsorption experiments were carried out in batch mode at varying temperatures (20°C, 25°C, 30°C, 35°C, and 40°C).

For each experiment, 1 g of the biomass was added to 100 mL of the metal solution in a 250 mL Erlenmeyer flask.

The flasks were placed in a temperature-controlled water bath and agitated at a constant speed of 100 rpm for 2 hours.

After the adsorption period, samples were filtered using Whatman filter paper to separate the biomass from the solution.

Table 7 : Effect of Temperature

Tempera ture (°C)	Ric e Hu sk (Cd mg/ g)	Sugarc ane Waste (Cd mg/g)	Coco nut Wast e (Cd mg/g)	Ric e Hu sk (F mg/ g)	Sugarc ane Waste (F mg/g)	Coco nut Wast e (F mg/g)	Ric e Hu sk (Cr mg/ g)	Sugarc ane Waste (Cr mg/g)	Coco nut Wast e (Cr mg/g)	Ric e Hu sk (As mg/ g)	Sugarc ane Waste (As mg/g)	Coco nut Wast e (As mg/g)
20	5.0	2.0	1.5	0.8	0.4	0.5	1.5	0.7	0.5	0.7	0.3	0.4
25	6.5	2.8	2.0	1.0	0.5	0.6	2.0	1.0	0.8	0.9	0.4	0.5
30	8.0	3.5	2.7	1.2	0.6	0.8	2.5	1.5	1.0	1.1	0.5	0.6
35	9.5	4.2	3.5	1.5	0.8	1.0	3.0	1.8	1.3	1.4	0.6	0.8
40	10.5	5.0	4.0	1.8	1.0	1.2	3.5	2.0	1.5	1.6	0.7	1.0

The outcomes of this study indicate a clear trend in the effect of temperature on the adsorption capacities of heavy metals by different biomass materials. As temperature increased from 20°C to 40°C, the adsorption capacities for cadmium, fluoride, chromium, and arsenic showed a consistent upward trend for all biomass materials assessed.

Rice husk exhibited the highest adsorption capacity across all temperatures, particularly for cadmium and chromium. This can be attributed to its larger surface area and favorable structural properties, which enhance the interaction with metal ions. Sugarcane waste and coconut waste also displayed increased adsorption with rising temperature; however, they remained less effective than rice husk in binding the heavy metals.

The increase in temperature may enhance the diffusion of metal ions and improve the rate of chemisorption, leading to greater uptake by the biomass materials. Higher temperatures can also reduce the viscosity of the solution, allowing for better mixing and contact between the biomass and metal ions. These findings underscore the potential of agricultural biomass, particularly rice husk, as a cost-effective and sustainable biosorbent for the removal of heavy metals from contaminated water sources. This study provides critical insights for future research and practical applications in water treatment technologies. Further investigations may explore the synergistic effects of temperature with other variables (such as pH and contact time) to optimize the adsorption process.

2. CONCLUSION

This study highlights the effectiveness of utilizing agricultural waste materials, specifically rice husk, coconut waste, and sugarcane waste, for the adsorption of heavy metals and fluoride from water sources in Delhi and Haryana. Analysis of 160 water samples from the Yamuna River revealed varying concentrations of heavy metals, underscoring the need for remediation solutions. The preparation of biomass through drying, crushing, and acid treatment significantly enhanced its adsorption potential by increasing cellulose content and introducing new functional groups. Rice husk demonstrated superior adsorption capacities for cadmium, chromium, arsenic, and fluoride, particularly at optimal pH levels and specific agitation conditions. The results indicated that factors such as contact time, agitation speed, and temperature played crucial roles in enhancing adsorption efficiency, with rice husk consistently outperforming the other biomass types. This study underscores the viability of agricultural wastes as low-cost, sustainable adsorbents for environmental remediation, promoting better waste management and water treatment practices. Future research should focus on the regeneration of these biomass materials and their applications in real-world wastewater treatment scenarios to further harness their potential in safeguarding water quality and environmental health.

3. REFERENCES

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