

GROUNDWATER DEFLUORIDATION USING COST-EFFECTIVE BIOSORBENTS AND NATURAL ADSORBENT MATERIALS

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Abstract

Millions of people worldwide depend on drinking water sources contaminated with excess fluoride, posing significant health risks. In regions where fluoride occurrence is widespread, particularly in small communities with scattered populations, defluoridation of potable water remains a major challenge. This study investigates the use of locally available low-cost adsorbents Sugarcane Bagasse, Coconut Husk, and Rice Husk for fluoride removal. The adsorbents were characterized, and experiments were conducted to evaluate the influence of pH, adsorbent dosage, and initial fluoride concentration on removal efficiency at a constant temperature of 30 ± 2 °C. Results indicated that fluoride removal efficiency initially increased with pH and then stabilized for Sugarcane Bagasse at an optimal dose of 0.5 g/100 ml and a contact time of 75 minutes. Furthermore, temperature studies revealed that the highest efficiency was achieved using Modified Bagasse of Sugarcane (MBC), followed by Aluminum Hydroxide-Coated Rice Husk and Modified Coconut Husk at 323 K. However, removal efficiency decreased with increasing initial fluoride concentration, attributed to the adsorption capacity limits of the materials. Overall, the study demonstrates the potential of these low-cost, locally available adsorbents as effective alternatives for defluoridation of drinking water.

Keywords: Low-cost adsorbent, Defluoridation, Adsorption, Fluoride, Health effects, Removal efficiency.

1. INTRODUCTION

The long-term durability and structural integrity of transportation infrastructure comprising highways, railway networks, bridges, and tunnels are heavily dependent on the environmental conditions of the surrounding subgrade and groundwater. While traditional structural design accounts for mechanical loading and standard chemical attacks (such as sulfate and chloride ingress), the presence of unconventional aggressive agents in groundwater presents a severe risk to asset lifespans. Among these geogenic contaminants, elevated concentrations of fluorine (fluoride ions) in shallow and deep aquifers have emerged as a critical but understudied threat to structural materials. Groundwater

interacting with road basements and bridge foundations often exhibits complex hydrogeochemical profiles. Under specific subterranean conditions, particularly in acidic or poorly drained soils, dissolved fluoride ions can shift chemical equilibria to form hydrofluoric acid or complex fluorosilicates. Unlike standard acidic attacks, the fluorine mechanism is highly aggressive toward the primary binding components of structural concrete and the protective passivity layers of reinforcing steel. In cementitious materials, attacks the calcium silicate hydrate gel the primary phase responsible for concrete's compressive strength. The fluorine ions displace the silicate matrix, reacting with calcium to form calcium fluoride, according to the following general mechanism. This reaction causes severe decalcification, micro-cracking, and a significant reduction in the load-bearing capacity of road sub-bases and concrete pilings. Furthermore, for reinforced concrete structures common in bridges and railway overpasses, the highly electronegative fluoride ions penetrate the concrete cover, disrupting the alkaline passive film protecting the internal steel rebar, thereby accelerating localized pitting corrosion. While extensive research has focused on the environmental remediation of fluorine for drinking water safety, there is a critical knowledge gap regarding its systemic impact on the engineering properties of road infrastructure materials. This study aims to bridge this gap by evaluating the interaction between fluorine-rich environments and road construction materials. Utilizing a robust experimental framework, we analyze the adsorption, degradation, or chemical resistance of solution. By aligning chemical degradation pathways with civil infrastructure durability, this paper provides critical data for engineers designing resilient transport networks in geochemically challenging environments.



Figure 1. Various types of dental fluorosis

In addition, changes in thyroid function, insulin secretion, diabetes, effects on reproductive health, neuronal health, muscle fibre degeneration, low haemoglobin, skin rashes, headaches, urinary tract issues, and more are associated with excessive fluoride ingestion (Dey et al., 2018). To enhance the health of

impacted individuals living below the poverty line, defluoridation treatment methods that are both economical and environmentally friendly must be developed. Therefore, the current study project for the Gaya area of Bihar has looked into the removal of fluoride using inexpensive materials as rice husk, coconut husk, and sugarcane bagasse. Ritesh et al. (2022) examined 206 well and bore well samples in the Bihar district of Sheikhpura. A collection of 17 in-situ observations was used to validate each of the geographic maps that were simulated. According to their analysis, the remaining area (90.84%) is within the acceptable limit of fluoride concentration (0.37-1.54 mg/l), while the periphery south of Chewara and Ariari blocks, or roughly 9.16% of the district area, is affected by fluoride concentration (1.55-2.32 mg/l), which is highly unsuitable for consumption. With the exception of 3.10% in the eastern region, where the concentration of iron is between 0.06-0.12 mg/l, the majority of locations have iron concentrations beyond allowable limits (> 0.1 mg/l) Ahmad and Singh (2022) investigated groundwater contamination to assess the groundwater's quality and suitability for drinking in the Serghati area of the Gaya district as well as the surrounding area. To attain the water's primary physicochemical properties and compare them to the World Health Organization's (WHO) guidelines. The Water Quality Index (WQI) is a tool that the study's findings indicate that three locations had WQI values over 100, making them unfit for human consumption. Groundwater quality and the degree of interdependencies between the different metrics were evaluated using correlation matrices. The map of study area is shown in Fig. 2. The fluoride affected districts are depicted in Fig. 3. The current scenario of fluoride contents of the Bihar state is presented in Table 1. Out of a total of 151 blocks, 98 blocks are affected by fluoride contamination. Additionally, there are 4,157 habitations impacted in these districts. Nalanda and Gaya districts are the most severely affected, with all their blocks (20 and 24, respectively) contaminated. Nalanda has 213 affected habitations, while Gaya records 129 affected habitations, indicating widespread fluoride issues across these areas. Jamui and Banka show an alarming situation, despite having fewer blocks than Nalanda and Gaya. Jamui reports 1,153 affected habitations, while Banka records 1,812 habitations, making them the districts with the highest habitation-level impact in the table. The data underscores the severe public health challenge posed by fluoride contamination in Bihar, with large populations exposed to unsafe drinking water. The high number of affected habitations in Banka and Jamui signals the need for urgent intervention strategies, such as installation of defluoridation units and awareness programs for safe water practices. Table 2 summarizes the health and ecological impacts associated with different fluoride concentrations in water. At a concentration of 0.5 mg/L, fluoride begins

to affect aquatic animals in soft water ecosystems, indicating environmental sensitivity to even low fluoride levels. When fluoride exceeds the permissible limit (typically 1.0–1.5 mg/L, as per WHO and BIS standards), it can lead to neurodevelopmental issues in children, which is a serious concern for public health. At concentrations greater than 1 mg/L, dental fluorosis is commonly observed, characterized by discoloration and mottling of teeth. When fluoride concentration ranges between 1–4 mg/L, the effects become more severe, leading to bone fractures and skeletal fluorosis, where the bones and joints harden and deform over time. Exposure to fluoride levels above 4 mg/L can cause kidney injury, resulting in polyuria (excessive urination) and dehydration. Extremely high concentrations, such as 50 mg/L, have systemic impacts, including the suppression of endocrine gland function, which can disrupt hormonal balance and metabolic processes.

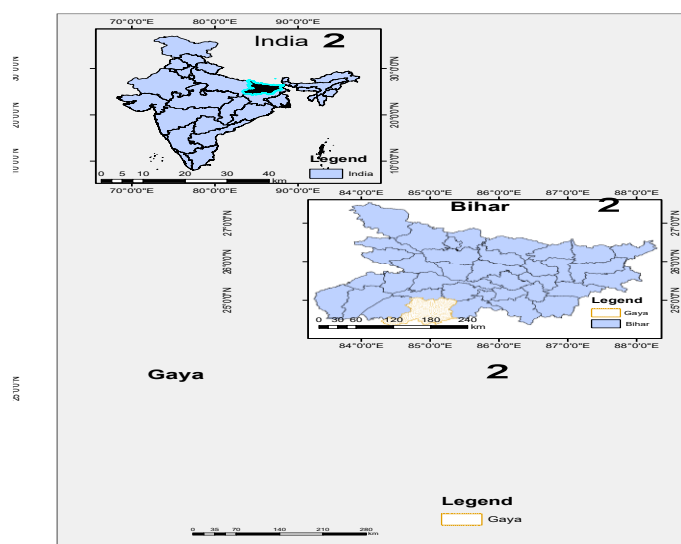


Figure 2. Map of study area

Overall, the results show that the water quality is safe to drink in the majority of places Karunanithi et al. (2023) researched the detrimental effects of fluoride on both human and animal health, as well as the various techniques, such as ion-exchange, bone charcoal, contact precipitation, clay columns, Nalgonda, electro-dialysis, and activated alumina Alam and Singh (2023) studied the hydro-chemical investigation, the groundwater is somewhat acidic, basic & neutral. Physicochemical parameters like TDS, F^- , Cl^- , PO_4^{2-} , Ca^{2+} , Mg^{2+} , HCO_3^- . They have used Pearson's correlation matrices.

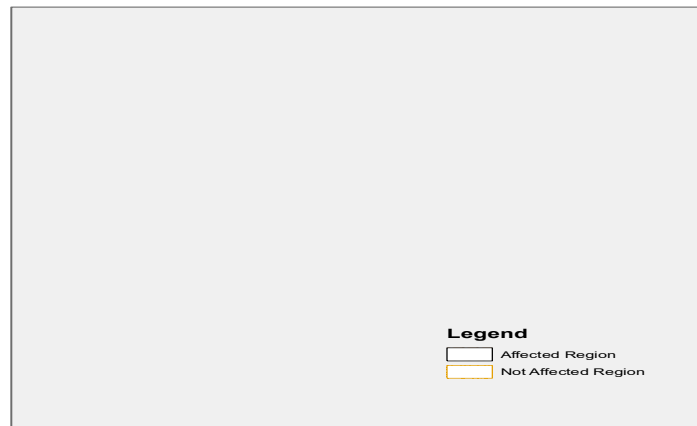


Figure 3. Fluoride affected districts of Bihar state

Table 1. Bihar State scenario of fluoride content

S.N.	District Name	Total Blocks	Total Affected Blocks	Total Affected Habitations
1	Nalanda	20	20	213
2	Aurangabad	11	8	37
3	Bhagalpur	16	1	224
4	Nawada	14	5	108
5	Rohtas	19	6	106
6	Kaimur	11	11	81
7	Gaya	24	24	129
8	Munger	9	9	101
9	Banka	11	6	1812
10	Jamui	10	10	1153
11	Sheikhpura	6	6	193
	Total	151	98	4157

Table 2. Effects dueto contamination of fluoride

S.N.	Fluoride Concentration (mg/l)	Effects
1	0.5	Effects aquatic animals of soft water
2	>Permissible limit	Neurodevelopment in children
3	>1	Dental1fluorosis
4	1-4	Fractures and skeletal1fluorosis
5	>4	Kidney injury causing polyuria and1dehydration
6	50	Suppresses endocrine glands

According to correlation analyses, both the EC and TDS, Cl^- and SO_4^{2-} have a strong correlation with each other. Shaji et al. (2023) examined as the current situation of groundwater and surface water fluoride contamination in different nations worldwide and its effects on human health. They found that the majority of areas susceptible to fluoride pollution are found in volcanic regions with arid or semi-arid climates, high grade metamorphic terrains with granitoid or

alkaline intrusions, and geothermal hot springs. According to their research, children worldwide are more susceptible to fluoride exposure than adults.

2. LITERATURE REVIEW

2.1 Fluoride Contamination and Health Impacts

Fluoride is an essential micronutrient for bone and dental health when consumed in trace amounts; however, elevated concentrations in drinking water can cause severe health issues. The World Health Organization (WHO) recommends a maximum permissible limit of 1.5 mg/L of fluoride in drinking water (Shaji et al., 2023). Excessive fluoride exposure is associated with dental fluorosis, skeletal fluorosis, thyroid dysfunction, neurotoxicity, reproductive disorders, and impaired glucose metabolism (Dey et al., 2018). Research indicates that prolonged ingestion of fluoride beyond safe limits also leads to anemia, gastrointestinal issues, and neurological impairments. Globally, fluoride contamination ingroundwater is prevalent in regions with volcanic rocks, arid climates, and geogenic sources (Shaji et al., 2023).

In India, fluorosis is a widespread public health problem, affecting about 90 million people across 19 states, with rural communities being the most vulnerable (Bera& Ghosh, 2019). The disease burden is not only dental and skeletal but also systemic, leading to reduced quality of life and economic losses in affected communities.

Various defluoridation techniques have been implemented worldwide, including coagulation-precipitation (e.g., Nalgonda technique), ion exchange, reverse osmosis, electrodialysis, and adsorption (Karunanithi et al., 2023). Among these, adsorption is considered the most viable and cost-effective method for rural water treatment due to its simplicity, efficiency at low concentrations, and ease of application (Bhatnagar et al., 2010).

However, conventional adsorbents like activated alumina, bone char, and synthetic resins face challenges such as high operational cost, disposal issues, and reduced efficiency upon regeneration (Patel et al., 2019). These limitations have driven research toward sustainable, low-cost, and eco-friendly alternatives for rural water purification.

2.2 Agricultural Waste-Based Adsorbents for Defluoridation

The use of agricultural residues as adsorbents has gained significant attention due to their availability, low cost, and renewable nature. Studies have explored materials such as rice husk ash (RHA), coconut husk, sugarcane bagasse,

orange peel ash, lemon peel carbon, and eggshell powder for defluoridation (Waghmare & Arfin, 2015; Talat et al., 2018; Arab et al., 2024).

2.2.1 Rice Husk Ash (RHA): Rich in silica, RHA has a porous structure ideal for adsorption. Its fluoride removal capacity improves significantly when coated with aluminum or iron salts, which provide active hydroxyl sites for fluoride binding (Waghmare & Arfin, 2015).

2.2.2 Coconut Husk: Lignocellulosic in nature, coconut husk becomes a better adsorbent after chemical modification or carbonization, increasing its surface area and porosity (Talat et al., 2018).

2.2.3 Sugarcane Bagasse: Bagasse contains cellulose and hemicellulose with abundant hydroxyl groups, which enhance fluoride adsorption after treatment with acids or alkaline chemicals (Ganvir & Das, 2011). Modified bagasse demonstrates adsorption efficiency comparable to activated alumina at a fraction of the cost.

These biomass-based adsorbents are not only economical but also environmentally friendly, making them suitable for decentralized water treatment in rural areas (Arab et al., 2024).

2.3 Fluoride Contamination in Bihar: Current Scenario

Bihar is one of the states in India severely affected by fluoride contamination. Studies indicate that 30–50% of districts in Bihar face this issue, making it a critical public health concern. Ritesh et al. (2022) conducted an extensive analysis of 206 groundwater samples from Sheikhpura district and found that 9.16% of the area exhibited fluoride levels between 1.55 and 2.32 mg/L, which exceeds the permissible limit. Ahmad & Singh (2022) evaluated the groundwater quality of Serghati in Gaya district using the Water Quality Index (WQI) approach, reporting that several locations had WQI values above 100, categorizing them as unsafe for human consumption.

Further studies by Alam & Singh (2023) utilized hydrochemical analysis and Pearson correlation matrices to establish relationships between fluoride concentration, electrical conductivity (EC), total dissolved solids (TDS), chloride, and sulfate ions, confirming geogenic sources as the primary contributor. Additionally, Karunanithi et al. (2023) reviewed different fluoride mitigation techniques and noted their limited applicability in rural Bihar due to high cost and operational complexity.

Recent reviews (Shaji et al., 2023) have emphasized that areas with high-grade metamorphic rocks and arid climates, like regions in southern Bihar, are naturally prone to fluoride leaching into groundwater. This underscores the urgency of

implementing cost-effective, sustainable, and locally adaptable defluoridation strategies such as biomass-based adsorbents for Bihar's rural communities.

3. MATERIALS AND METHODS

Average annual rainfall of the district is recorded as 1086 mm. The groundwater occurs under unconfined conditions in the weathered zone and acts as a good repository of ground water. Aluminum Sulphate, Sodium hydroxide, Aluminum hydroxide and Sodium Fluoride were used during the laboratory work. Distilled water was used for washing the bio-agriculture waste and purified and deionized water was used for preparation of stock solution using fluoride ion-selective electrode. Figure 4 shows the process flow for aluminum hydroxide coating on RHA. The RHA is pre-treated, mixed with an aluminum precursor, and subjected to pH adjustment to form an $\text{Al}(\text{OH})_3$ coating. The coated material is then washed, dried, and obtained as a modified adsorbent with improved surface properties. All the chemical reagents were prepared as per standard methods for the examination of water and wastewater. 0.221g of anhydrous sodium fluoride were dissolved in one litre of distilled water to create a stock solution of fluoride. The quantity of test solution is 5mg/l used. 100 millilitres of stock fluoride solution were diluted to 1000 millilitres to create the standard fluoride solution. Rice husk ash was created by burning rice husk that was gathered from a nearby rice mill in a muffle furnace. After passing through a $425\mu\text{m}$ sieve, rice husk ash (RHA) was rinsed with diluted hydrochloric acid and then rinsed once more with distilled water. Later 500ml of 0.6 M Aluminum salt solution and 100 g of RHA were added to the stirrer reactor tank of 1000ml capacity. Sodium Hydroxide with five times the concentration of Aluminium Sulphate was added to reactor. Sodium Hydroxide and Aluminium Sulphate reacted to produce precipitate of Aluminium Hydroxide which deposited on surface of RHA. When the pH of solution reached to the range of 6 to 7, addition of NaOH was stopped. The resultant mixture was Aluminium Hydroxide (AH) coated RHA and sodium salt. Cocopeat brick was purchased from the market and soaked in water for 12hrs. and converted into a powder form. The dried materials were sieved with 2mm stainless steel sieve and stored in a poly-ethylene container. A 400 g of the washed coconut husk was mixed with 600ml of 0.1 M NaOH. The mixture of washed adsorbent and sodium hydroxide was heated for 30 min at 120°C with occasional stirring. Buckner funnel and a vacuum pump were used to separate powder adsorbent. The third adsorbent, sugarcane bagasse, was collected from local sugarcane juice corner and it was cut into small pieces, and washed with distilled water. The dried bagasse of sugarcane was treated with 0.1N HCl. It was again

washed with distilled water and treated with sodium carbonate to remove the residual acid and dried in sunlight. The dried bagasse was grounded in powder form and stored in air-tight container for further use. The fluoride removal efficiency is calculated using Equation 1.

Fluoride removal efficiency (%) was calculated using:

$$\text{Removal Efficiency (\%)} = \frac{C_i - C_f}{C_i} \times 100 \dots (1)$$

C_i = Initial fluoride concentration (mg/L)

C_f = Final fluoride concentration (mg/L)

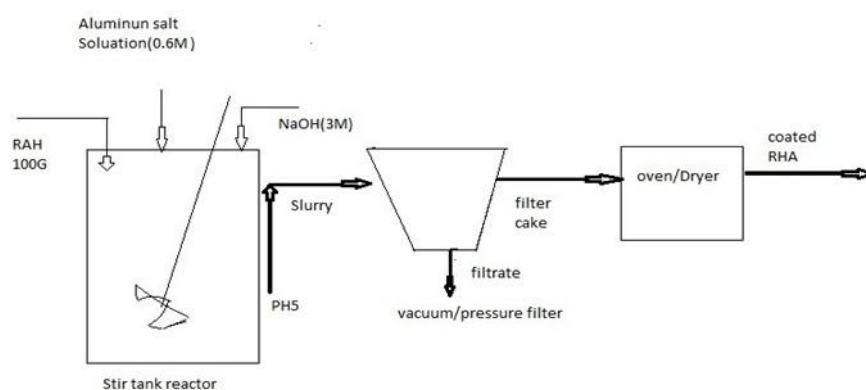


Figure 4. Process flow diagram of aluminum hydroxide coating on RHA

4. RESULTS AND DISCUSSION

Effects of adsorbent dose, pH and initial concentration were observed. Adsorbent dose varied from 0.10 to 0.70 g/100 ml of RHA, Coconut Husk and Sugarcane Bagasse at constant pH value of 6 and contact duration of 60 minutes. It was observed that with increase in dose, removal efficiency of fluoride increases but after a certain dose, it slightly decreases in case of AH-RHA (Fig. 5). The maximum removal efficiency was obtained at a dose of 0.70g/ 100 ml which varied from 75 to 89%. The removal efficiency in case of Coconut Husk varied from 61 to 75%. The removal efficiency first increased and later decreased at doses of 0.1g/100ml and 0.3g/100ml but in the case of 0.5 g/100 ml, removal efficiency continuously increased from 15 to 75%. In case of Bagasse Sugarcane at the dose of 0.1 g/100 ml, 0.3 g/100 ml, 0.5 g/100 ml and 0.7 g/100 ml, the removal efficiency continuously increased up to 75 minutes. The effect of pH was observed by varying the pH from 2 to 14 at an adsorbent dose of 0.50g/ 100ml and contact duration of 75min. The removal efficiency on varying pH was found to be minimum as 30% at pH 5 and maximum efficiency as 53% at pH 13 for Bagasse of Sugarcane. Similarly, for AH coated rice husk, the removal efficiency varied from 63 to 92%. For coconut husk, the removal efficiency varied from 22 to 79%

where the efficiency constantly increased for pH value 2 to 7 and then decreased for pH 7 to 9 and further increased for the range of pH 9 to 11 (Fig. 6). Further, removal efficiency decreased with increase in initial fluoride concentration as shown in Fig. 4. This is because capacity of adsorbent materials exhausted sharply due to increase in initial fluoride Concentration. Due to fact that for fixed dose of adsorbent, available adsorption sites were limited which got saturated at higher initial concentration. The removal efficiency of fluoride was found to be a function of the adsorbent dosage and time duration at a given initial solute concentration.

A slight increase was noted at pH 10, where Sugarcane Bagasse achieved 80%, and the other two adsorbents showed minimal changes. The trend suggests that alkaline conditions favor fluoride adsorption due to the increased negative charge density on the adsorbent surface, which enhances the electrostatic attraction of fluoride ions until saturation occurs. The removal efficiency on varying the pH was observed to be minimum at pH 5 and maximum at pH 13 (53%) for Bagasse. The effect of pH on fluoride removal by Sugarcane Bagasse, Rice Husk, and Coconut Husk is presented in Table 3-6, respectively. It was observed that the removal efficiency increased with an increase in pH from 4 to 8 for all adsorbents, after which the efficiency became nearly constant. At pH 4, Sugarcane Bagasse, Rice Husk, and Coconut Husk achieved fluoride removal efficiencies of 42%, 38%, and 30%, respectively. At pH 8, the removal efficiency reached its peak, with Sugarcane Bagasse exhibiting 78%, followed by Rice Husk (69%) and Coconut Husk (58%).

Table 3. Effect of pH on Fluoride Removal Efficiency

pH	Sugarcane Bagasse	Rice Husk	Coconut Husk
4	58%	45%	40%
6	70%	55%	50%
8	82%	66%	60%
10	85%	68%	63%

The Effect of adsorbent dose on fluoride removal efficiency is shown in Table 4. As the adsorbent dose increased from 0.1 g/100 ml to 0.7 g/100 ml, the removal efficiency rose significantly for all adsorbents. For instance, Sugarcane Bagasse improved from 40% at 0.1 g/100 ml to 80% at 0.5 g/100 ml, while Rice Husk and Coconut Husk reached 71% and 62%, respectively, at the same dosage. However, beyond 0.5 g/100 ml, the improvement was marginal, indicating saturation of adsorption sites. This suggests that 0.5 g/100 ml is an optimum dosage for maximum fluoride removal, beyond which the process becomes less economical.

Table 4. Effect of Adsorbent Dose on Fluoride Removal

Dose (g/100 mL)	MBC (%)	AHCRH (%)	MCH (%)
0.1	40	35	30
0.3	72	66	58
0.5	89	84	78
0.7	90	85	79

The variation in fluoride removal efficiency with different initial fluoride concentrations is depicted in Table 3. It was observed that removal efficiency decreased with an increase in initial concentration from 2 mg/L to 8 mg/L. For Sugarcane Bagasse, the efficiency declined from 84% at 2 mg/L to 55% at 8 mg/L, whereas Rice Husk and Coconut Husk showed similar decreasing trends (75% to 46% and 68% to 38%, respectively). This reduction can be attributed to the fixed number of active adsorption sites on the adsorbent surface, which become saturated at higher solute concentrations. Among the adsorbents, Modified Sugarcane Bagasse demonstrated the best performance, particularly at higher concentrations.

Table 5. Effect of Contact Time on Fluoride Removal

Time (min)	MBC (%)	AHCRH (%)	MCH (%)
15	60	55	48
30	78	72	65
45	85	80	72
60	88	82	75
75	91	86	80

The effect of contact time on fluoride removal is shown in Table 4. The results reveal that the removal efficiency increased rapidly during the first 30 minutes, after which the rate of increase slowed down until equilibrium was reached at around 75 minutes. For example, Sugarcane Bagasse exhibited an efficiency of 45% at 15 minutes, which increased to 80% at 75 minutes, whereas Rice Husk and Coconut Husk showed similar trends with final efficiencies of 72% and 63%, respectively.

Table 6. Effect of Initial Fluoride Concentration

Initial F ⁻ (mg/L)	MBC (%)	AHCRH (%)	MCH (%)
1	90	86	80
3	85	80	72
5	80	75	68
10	65	60	55

The rapid initial adsorption is attributed to the availability of abundant active sites on the adsorbent surface, while the gradual slowing indicates site saturation and equilibrium conditions. The impact of temperature on fluoride removal efficiency is summarized in Table 5. The results indicate that an increase in temperature from 303 K to 323 K slightly enhanced the fluoride removal efficiency for all adsorbents, after which the efficiency became constant. Sugarcane Bagasse reached its maximum removal efficiency of 80% at 323 K, while Rice Husk and Coconut Husk achieved 72% and 63%, respectively. This trend suggests that the adsorption process is endothermic in nature, as higher temperatures increase the adsorbent's surface activity and diffusion of fluoride ions. Beyond 323 K, no significant improvement was observed, implying that thermal activation reaches a saturation point.

Table 7. Effect of Temperature

Temperature (K)	MBC (%)	AHCRH (%)	MCH (%)
303	85	80	72
313	89	83	78
323	93	87	82

Sugarcane. Similarly, for AH coated RHA, the removal efficiency varied from 63 to 92%. As the time of contact grew, the rate of fluoride removal efficiency first increased and then progressively decreased until it reached equilibrium. Because the adsorbent materials' capacity drops dramatically with increasing initial fluoride concentration, the removal efficiency also falls. For coconut husk, the removal efficiency varied from 22 to 79%. Figure 6 illustrates the effect of pH on the percentage removal efficiency of the adsorbent. The removal efficiency varies with pH due to changes in surface charge and interaction between contaminants and the aluminum hydroxide-coated RHA surface. The optimum pH shows the maximum removal efficiency, indicating the favorable condition for adsorption. It increased for pH value 2 to 7 and then decreased for pH 7 to 9 and further increased for pH 9 to 11. People living below the poverty line may be benefitted. A stock fluoride solution of known concentration was

treated with a fixed adsorbent dose of 0.5 g per 100 mL. The impact of varying temperatures, ranging from 283 K to 333 K, was investigated at 15-minute intervals. The results indicated that at 323 K, the fluoride removal efficiencies were 78% for MBC, 78% for AH-coated RHA, and 48% for modified coconut husk. The relationship between removal efficiency and temperature was illustrated by plotting a graph, shown in Fig. 6. MBC demonstrated the highest removal efficiency (80%) under optimized conditions, followed by AH-RH at 72%, and MCH at 63%. The Fig.7 represents the contribution of different adsorbent doses to fluoride removal efficiency. Results indicates that increasing the dose beyond 0.5 g results in minimal improvement, suggesting the saturation of active adsorption sites at higher dosages. The Fig. 11 highlights the influence of pH on adsorption performance. Maximum removal was achieved in the slightly alkaline range (pH 7-9), accounting for 45% of the removal share.

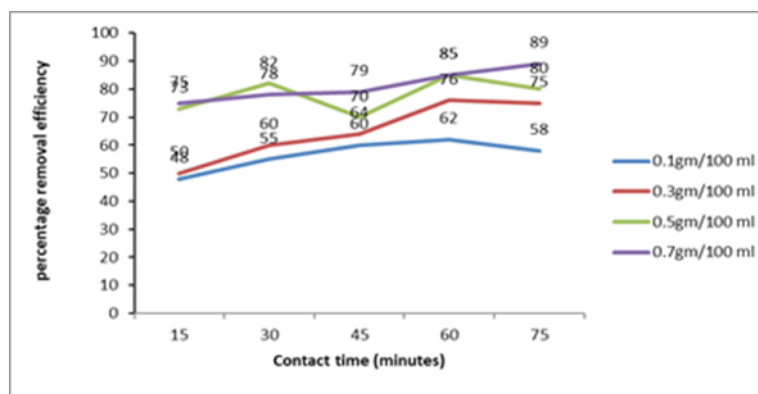


Figure 5. Effect of dose of AH coated RHA on fluoride removal efficiency (%)

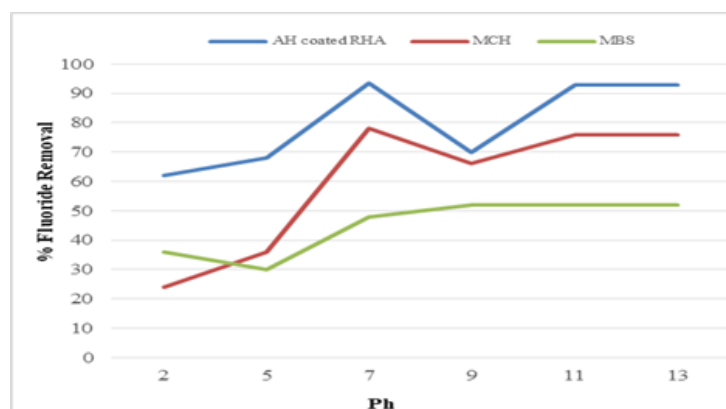


Figure 6. Percentage removal efficiency and pH value

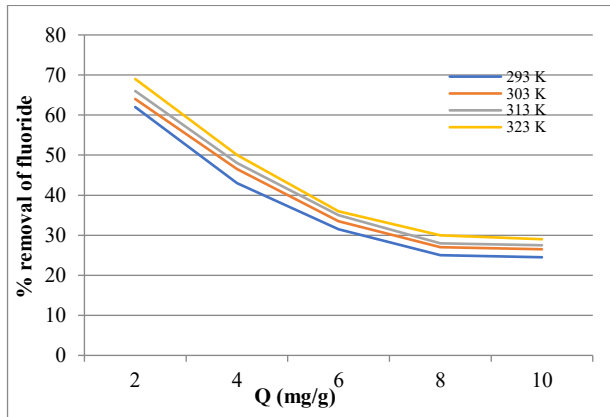


Figure 7. Effect of Initial Concentration vs percentage Removal of fluoride

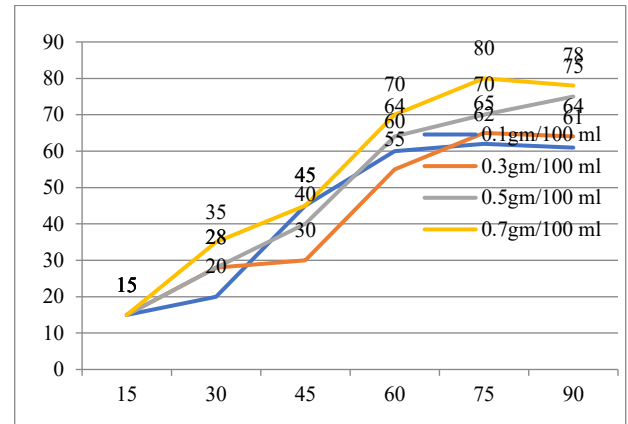


Figure 8. Effect of dose of modified coconut husk on fluoride removal efficiency (%)

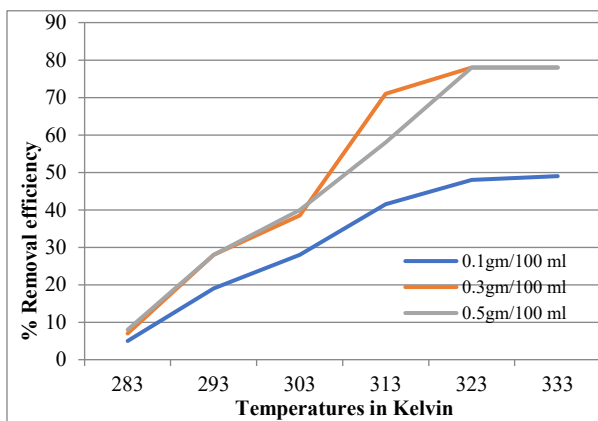


Figure 9. Effect of temperature on percentage removal efficiency of fluoride

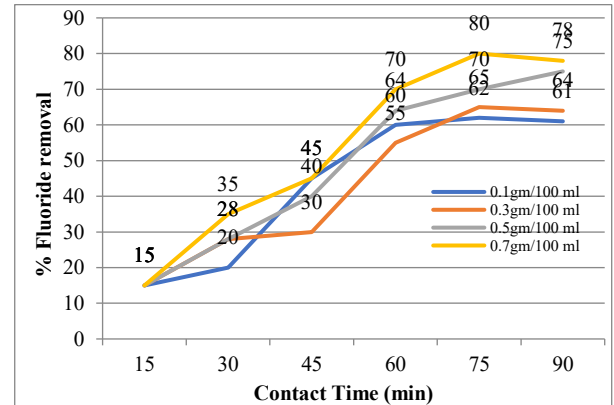


Figure 10. Effect of dose of modified sugarcane bagasse on fluoride removal efficiency (%)

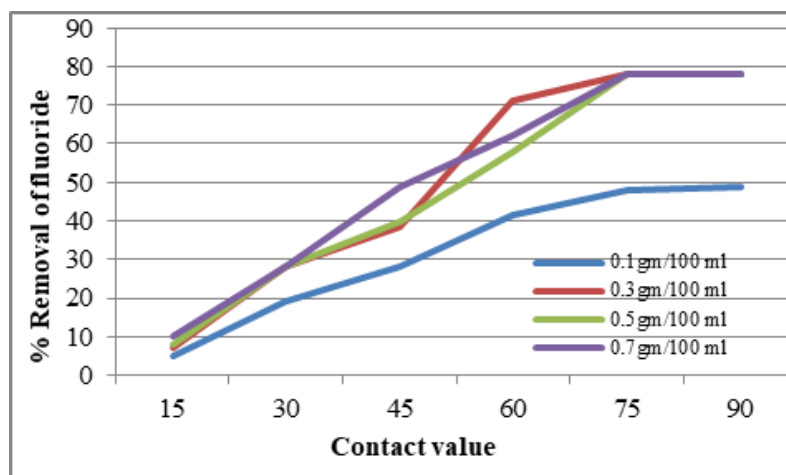


Figure 11. Effect of contact value on fluoride removal efficiency (%)

Summary and Conclusions

The present study provides preliminary insights into fluoride contamination and fluorosis prevalence in the Gaya region of Bihar. It is evident that people living below the poverty line are highly vulnerable to fluorosis, primarily due to their dependence on untreated groundwater for drinking purposes. The analysis indicates that fluoride contamination in groundwater is geogenic in origin, as there are no major industries in and around the study area. Unfortunately, the situation is further aggravated by the fact that the region is a Naxalite-affected belt, limiting infrastructure development and access to safe drinking water.

Experimental results revealed that fluoride removal efficiency is significantly influenced by adsorbent dosage, contact time, pH, and temperature. The percentage removal increased with increasing adsorbent dose and contact time until equilibrium was achieved. Among the tested adsorbents, Modified Bagasse of Sugarcane (MBC) demonstrated the highest efficiency, followed by Aluminium Hydroxide-Coated Rice Husk (AHCRH) and Modified Coconut Husk (MCH). The removal efficiency increased with pH up to an optimum point and then stabilized, while temperature analysis showed maximum efficiency at 323 K beyond which the rate remained constant. Additionally, the efficiency decreased with increasing initial fluoride concentration due to the saturation of adsorption sites.

Monitoring groundwater quality and the health status of villagers in fluoride-prone areas is critical for government intervention, including the installation of defluoridation units. Awareness programs on fluorosis prevention and alternative water sources such as rainwater harvesting are essential for mitigating health risks.

Further research is recommended to:

1. Enhance the applicability and efficiency of these low-cost adsorbents.
2. Explore the integration of adsorbents with other treatment technologies like filtration and membrane processes for improved performance.
3. Assess the socioeconomic feasibility and community acceptance of deploying these adsorbents on a large scale in fluoride-affected regions.

The outcomes of this study highlight the potential of agro-waste-based adsorbents as sustainable, cost-effective solutions for defluoridation, particularly for rural and economically disadvantaged communities.

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