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Removal of fluoride from drinking water through low-cost techniques

Hira Ishtiaq[1], **Norheen Amina**[1], **Amina Irfan**[1], **Habiba Mohsin**[1] **and Ahsan Shahbaz**[2]

[1] UOL, Civil Engineering Technology,54000, Lahore, Pakistan

[2] Pak Safety Solution, 54770, Lahore, Pakistan

Corresponding author:
Norheen Amina
archiengg_noor@yahoo.com

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Faculty of Civil Engineering and Architecture Osijek
Josip Juraj Strossmayer University of Osijek
Vladimira Preloga 3
31000 Osijek
CROATIA

Abstract:
Fluoride ions (F-) from natural sources or industrial wastewater are the main cause of many pathological conditions in people living in more than 25 countries. Thus, removing F- from drinking water is pivotal for preventing serious health consequences. The WHO recommends a limit of 1,5 mg/L for fluoride in drinking. Excessive amounts of fluoride in drinking water are prevalent in Pakistan, leading to related health risks. Low-cost techniques for the defluoridation of drinking water can be used. In this study, the removal of fluoride from drinking water by an adsorption method using low-cost materials/adsorbents, such as marble chips, wheat husks, rice husks, egg shells, concrete, fuller earth, fly ash, freshly fired bricks, and charcoal, at different contact times and different bed thicknesses was investigated. A batch sampling technique was used for sample collection. On average, marble chips, wheat husks, rice husks, egg shells, concrete, fuller earth, fly ash, freshly fired bricks, and activated charcoal (rice husk) resulted in 71,99 %; 90,99 %; 66,73 %; 90,99 %; 63,30 %; 71,99 %; 22,60 %; 49,67 %; and 90,13 % fluoride removal, respectively. Therefore, defluoridation using these materials is desirable. The performance of adsorbents depends on parameters such as contact time, depth of the adsorbent media, and pH. The bed thickness of the adsorbent has a minor effect on fluoride removal. The major contributors to fluoride removal from water are contact time and adsorbent composition.

Keywords:
defluoridation; drinking water; adsorption; low-cost adsorbents; waste materials

1 Introduction

Fluoride is present in all naturally occurring water, with drinking water being the largest contributor of fluoride regularly. Depending on its concentration, fluoride has beneficial and detrimental effects on human health. The strengthening of bones and prevention of tooth decay are some benefits of fluoride in the human body. Surplus exposure to fluoride in water can lead to diseases such as brittle bones, skeletal and dental fluorosis, impotence, brain damage, cancer, Alzheimer’s disease, and thyroid disorders [1]. Fluorine is an essential element of the human body. A daily dose of 0,5 mg/L is required for bone formation and enamel mineralization [2]. The WHO recommends a standard range of 0,5-1,5 mg/L fluoride in drinking water [1, 2]. It is necessary to maintain a standard range of fluoride in drinking water [2]. The occurrence of F- in the drinking water of Lahore is within the permissible range. However, neighbouring zones such as Mangamandi are perceived to have greater fluoride concentrations in their water sources. Health effects, such as dental and skeletal fluorosis, owing to the consumption of water containing high fluoride concentrations have also been reported [3]. The same scenario was stated for groundwater in the Kalat division of Balochistan (Mastung City) [4]. The Thokar Niaz Baig Village had fluoride concentrations exceeding the limit of 0,5-1,5 mg/L [5].

Water defluoridation can be achieved through different processes, including contact precipitation and adsorption/ion exchange and chemical additives and low-cost adsorbents [6, 7]. Different low-cost adsorbent materials such as horse gram powder, ragi powder, multani matti, red mud, calcined clay, concrete, pine apple peel powder, chalk powder, orange peel powder, rice husk, red mud, Moringa oleifera extract, gooseberry, activated alumina-coated silica gel, activated sawdust, activated coconut shell carbon, coffee husk, bone charcoal, and activated soil can be used for water defluoridation [6]. The effects of several factors, such as contact time, pH, adsorbent dose, and adsorbent concentration, on the fluoride removal efficiency should, however, be considered [8].

The wheat husk is a lignocellulosic waste product of about 15-20 % wheat. It has been revealed as an effective and economical adsorbent [6]. Freshly fired brick pieces can remove fluoride in domestic defluoridation units. In the brick bed of the unit, if the brick pieces are layered on top of burnt coconut shells and pebbles, the percentage of fluoride removed is 51,0-56,8 % [9]. Rice husk (RH) is the outer cover of the rice grains removed during the milling process and accounts for 20 % of the world’s total rice production. When using rice husk, 83% fluoride removal can be obtained, and after 180 min, the removal reaches an equilibrium point. When the pH of the solution is in the range of 2-10, marginal variation is achieved using rice husk [6]. The removal of fluoride from drinking water can also be achieved using fly ash, which can adsorb fluoride to the acceptable limits set by the WHO [10]. Broken concrete pieces can also remove fluoride from an aqueous solution, with 80 % of fluoride removal occurring after 120 min of contact time [11, 12]. Calcium-based adsorbents can remove fluoride from aqueous solutions. Calcium-based adsorbents show a standing empathy for fluoridation and can remove fluoride efficiently. They are biocompatible and inexpensive [13]. Neem leaves increased the fluoride concentration in a test solution from 2,5 mg/L to 3,8 mg/L as a low-cost adsorbent. Hence, this material is unsuitable for defluoridation [14].

The defluoridation of any material can be described by the chemical interaction of fluoride with metal oxides under suitable pH conditions [15]. The adsorbent dosage, concentration, particle size, and co-anions at neutral pH can be used to investigate defluoridation [16]. Thermodynamic investigations provided evidence of the exothermic nature of the adsorption process, which cannot be spontaneous. The adsorption kinetics followed a pseudo-second-order model [17]. In a study, adsorption efficiency was directly related to a temperature beyond 35 °C. An optimal reaction temperature was determined at 65 °C when the efficiency of the adsorbent was maximum. Eggshells have the potential to provide economic and environmental benefits by removing contaminants from wastewater [18]. In this study, low-cost multiform materials were used for the defluoridation of drinking water. Each adsorbent's efficiency and removal cost were investigated by varying the adsorbent bed thickness and contact time.

Based on the results, recommendations for low-cost techniques for fluoride removal were made. The effect of low-cost adsorbents on pH was also investigated.

2 Methodology of fluoride removal

2.1 Preparation of solution

The first step in the preparation of the solution was the preparation of distilled water. Distilled water was prepared in the Environmental Engineering Laboratory (UOL). After that, solutions of different concentrations of fluoride ranging from 5 mg/L to 20 mg/L were prepared [5]. Sodium fluoride salt was used, and a stock solution was prepared at varying concentrations.

2.1.1 Adsorbent Selection

To select an appropriate defluoridation material (Figure 1), the following measures were considered:

- capacity of fluoride removal,
- elementary design,
- easy accessibility of selected materials and chemicals at low cost,
- pre-treatment of material if required,
- perception of the method by consumers [19].

A filter bed was prepared using different low-cost adsorbents to purify the water, as shown in Table 1. For this purpose, Sargodha crush and sand were used along with coconut charcoal. A bottom layer of coconut charcoal was prepared at a depth of 15,24 cm. Afterward, a 10,16 cm thick layer of Sargodha crush and sand was laid [19]. After the preparation of the filter bed, layers of defluoridated material were laid at depths 7,62 cm and 15,24 cm.

Table 1. Available adsorbents

No	Materials	Availability	Properties	References
1	Wheat husk	Easily available in market	1-2 mm	[6]
2	Freshly fired bricks		Uncured freshly manufactured bricks red colour (20-40 mm)	[6, 9, 15]
3	Marble chips		Off-white (8–10 mm)	[6, 13, 20]
4	Eggshells		Hand crushed (1,0-1,5 mm)	[21]
5	Rice husk		1-2 mm	[6, 22]
6	Concrete	Concrete obtained from concrete lab students testing cylinder samples	Concrete with of ratio 1:2:4 (8–20 mm) high compressive strength, low permeability	[11]
7	Fly ash	Brick kiln	Ash from Brick kiln and chullah of (100 um)	[10]
8	Fuller earth (Multani Mitti)	Easily available in market	Multani mitti bought from the local market (0,25-0,06 mm), highly absorbent	[6, 11]
9	Activated charcoal (rice husk)	Produced at home	50-100 um	[6]

A batch technique was implemented for the experiments because of its ease of use. All the selected adsorbents were used individually for experiments in the container system. Water samples were collected every 3, 6, and 9 h [16, 17].

The amount of fluoride in the water samples was measured using a fluoride kit and a NOVA 60 at the Environmental Engineering Laboratory (UOL) for comparison with the NSDWQ and WHO guidelines.

Multani Mitti
Wheat Husk
Rice husk
Marble Chips
Freshly Fired Bricks
Egg Shells
Fly Ash
Crushed Concrete
Activated Charcoal (Rice Husk)

Figure 1. Selected low-cost adsorbents

3 Result of fluoride removal efficiency with selected adsorbents

This section describes the results and effects of various low-cost adsorbents (wheat husk, rice husk, fuller earth, concrete, freshly fired bricks, fly ash, marble chips, and eggshells) on fluoride removal efficiency. The effects of contact on the fluoride removal efficiency of the adsorbents were examined using absorbents laid at depths of 7,62 cm and 15,24 cm.

3.1 Marble chips

Using marble chips (Figure 2) at a 7,62 cm depth, almost 44,15 % of the fluoride in the test solution was removed in the first 3 h, and after 6 h of contact time, 97,67 % of fluoride in the test solution was removed. At 9 and 12 h, the fluoride concentration was detected below 0,1 mg/L. The same trend was also observed when a bed of 15,24 cm marble chips was used, i.e., from a time interval of 0 h to 6 h, the pH value changed from 6,5 to 10,4. In the first 3, 6, and 9 h, 57,90 %; 92,45 %; and 75,0 % of the fluoride was removed, and after 12 h, the fluoride concentration was measured as being below 0,1mg/L. Accordingly, by increasing the bed thickness, the fluoride removal efficiency increased owing to the greater absorption capacity of the adsorbent. The pH of the solution also increased, and the solution became alkaline because of the calcium component of the marble chips. However, the optimal time interval for F-removal was 6 h.

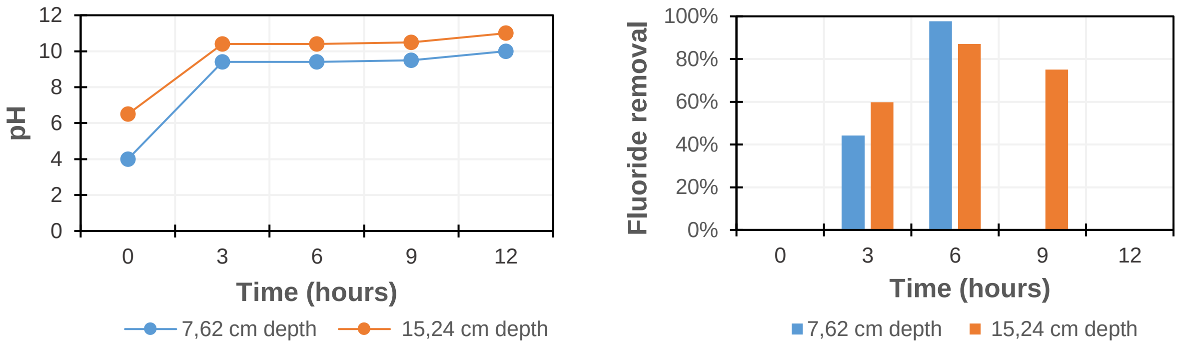

Figure 2. Change in pH and fluoride removal using marble chips

3.2 Rice husk

As depicted in Figure 3, the fluoride removal efficiency of rice husks placed at a depth of 7,62 cm was 3,89 % in the first 3 h, 82,40% in the following 3 h, and 92,3% after 9 h. After 9 h, the fluoride concentration was less than 0,1 mg/L. When a 15,24 cm bed of rice husks was employed, the same trend was observed: from 0 to 9 h, the pH value increased from 5 to 5,6, and then it declined to 4,8. In the first 3, 6, and 9 h, 47,57 %; 85,10 %; and 87,50 % of the fluoride was removed, respectively. After 12 h, the fluoride levels were below 0,1 mg/L.
Owing to the enhanced absorption capacity of the adsorbent, the fluoride removal efficiency increased as the bed thickness increased, and the pH was within the neutral zone. Consequently, the optimal time between F- removal and pH adjustment was determined to be 6 h.

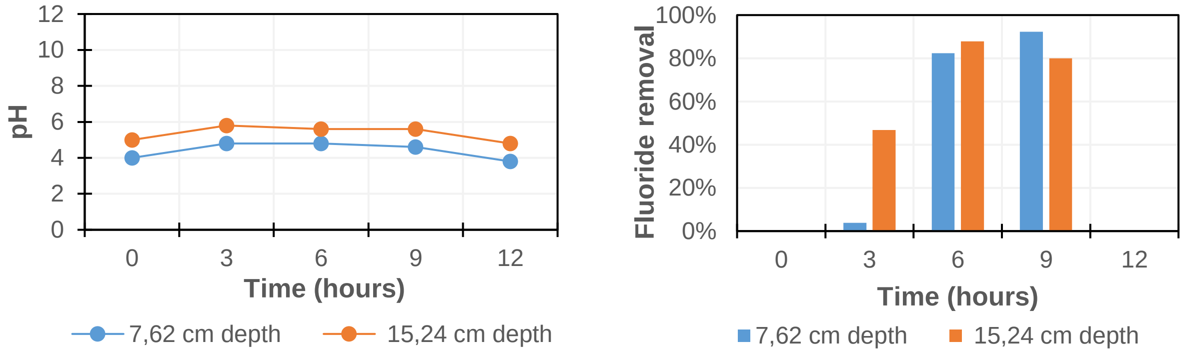

Figure 3. Changes in pH and fluoride removal when rice husks are used

3.3 Wheat husk

According to Figure 4, the removal efficiency of fluoride using wheat husks at a bed depth of 7,62 cm was 56,06 % in the first 3 h, and 98,27 % after 6 h. Furthermore, the concentration of fluoride fell below 0,1 mg/L after 6 h. When wheat husks bed of 15,24 cm was employed, the same pattern was observed: from 0 to 9 h, the pH value increased from 4,1 to 6,1, and after 9 h, it fell to 5,1. During the first 3 h and 6 h, the removal efficiencies were 61,08 % and 98,61 %, respectively, and the fluoride concentration fell below 0,1mg/L after 6 h. Based on these results, wheat husks followed the same pattern as rice husks.

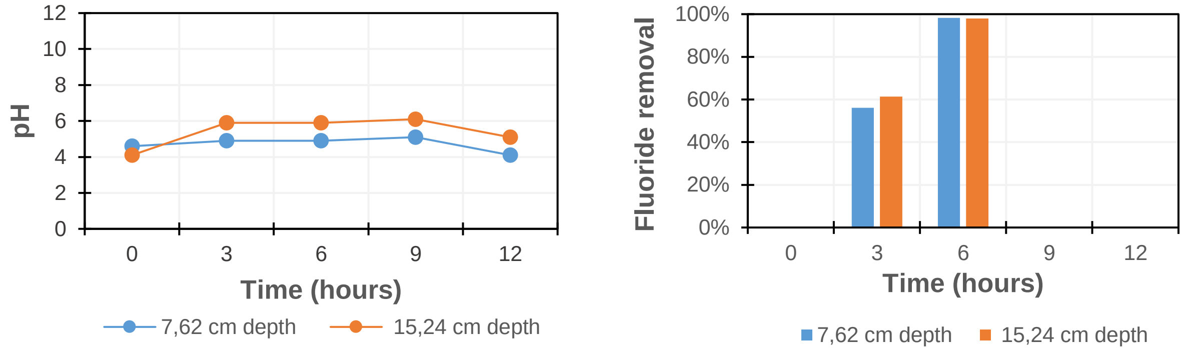

Figure 4. Changes in pH and fluoride removal when wheat husks are used

3.4 Egg shells

As seen in Figure 5, when egg shells are used at a depth of 7,62 cm, the removal efficiency of fluoride in the first 3 h was 99,24 %, and fluoride concentrations were below 0,1 mg/L thereafter. The same pattern was observed when a bed of 15,24 cm eggshells was utilized.

From 0 to 3 h, the pH increased from 5,6 to 7,9 and then fell to 6,6 after 9 h. The egg shells removed fluoride within 3 h. Increasing the thickness of the bed did not have an additional effect on fluoride concentration and pH. The pH increased by increasing contact time because the calcium carbonate in the egg shells neutralizes the pH. Calcium carbonate is quite effective in treating highly acidic wastewater (industrial area) and eliminates the corrosive properties of wastewater.

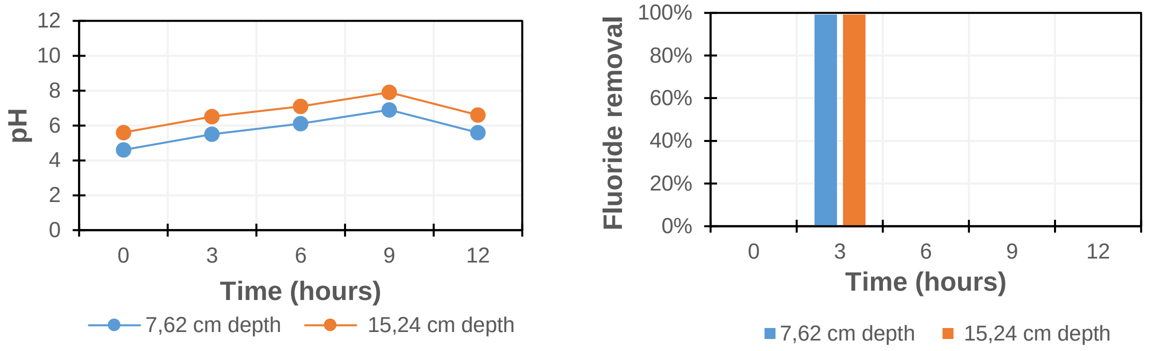

Figure 5. Changes in pH and fluoride removal when wheat husks and egg shells are used as absorbents

3.5 Concrete

As shown in Figure 6, when concrete fragments are utilized, the removal efficiency at a 7,62 cm depth was 84,50 % in the first 3 h, 19,73 % in the following 3 h, 20,88 % in the next 3 h, and 94,74 % after 12 h. The same tendency was also observed when a 15,24 cm bed was utilized. When concrete fragments were utilized, the pH dropped from 5,8 to 5,0 over the course of 12 h. In the first 3 h, 6 h, and 9 h, fluoride was eliminated at rates of 87,87 %; 35,00 %; and 92,31 %, respectively. After 12 h, the fluoride concentrations were below 0,1 mg/L.

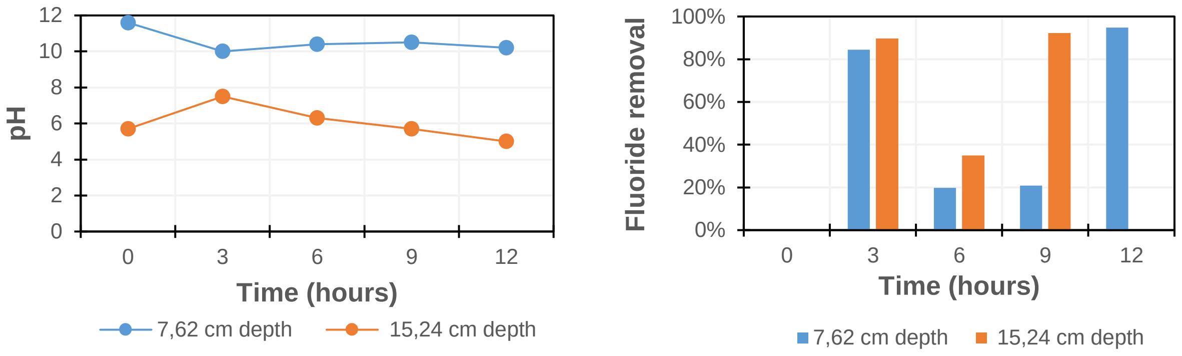

Figure 6. Changes in pH and fluoride removal when concrete is used as the absorbent

The fluoride removal efficiency was improved by increasing the bed depth. However, the optimal removal time for fluoride was 9 h at a depth of 15,24 cm. Concrete is appropriate for removing fluoride but is unsuitable for strongly acidic or alkaline water.

3.6 Fuller earth (Multani Mitti)

Using fuller earth, the removal efficiency at a depth of 7,62 cm was 55,55 % in the first 3 h, 65,00 % in the next 3 h, and 96,43 % in the following 3 h, as shown in Figure 7. After 9 h, the fluoride content was below 0,1 mg/L. A distinct pattern was also noticed when a bed of 15,24 cm fuller earth was utilized. From 0 to 12 h, the pH slightly increased from 6 to 7. In the first 3 h, 6 h, and 9 h, fluoride was eliminated at a rate of 64,50 %; 53,52 %; and 96,96 %, respectively; after 12 h, the fluoride concentration fell below 0,1mg/L.

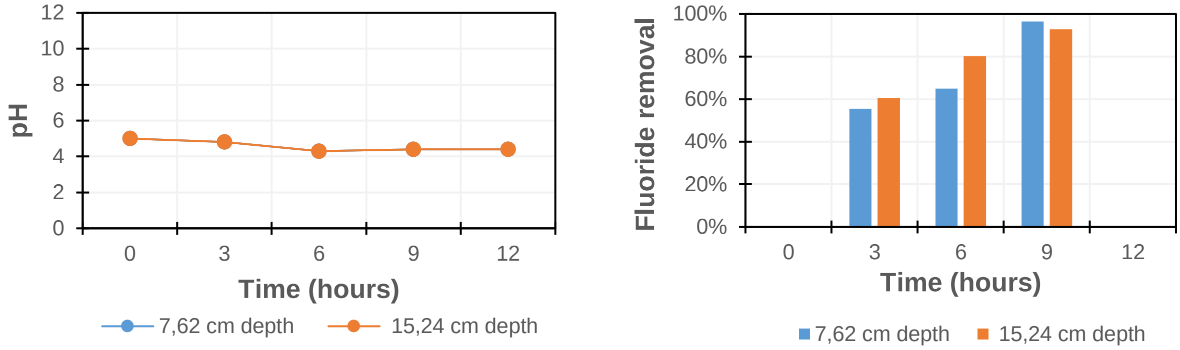

Figure 7. Changes in pH and fluoride removal when fuller earth was used as the absorbent

The fluoride removal efficiency increased with increasing depth, while the pH remained unchanged. However, the optimum F-removal interval was 9 h at a depth of 15,24 cm. Fuller earth is effective for the removal of fluoride in non-acidic water.

3.7 Freshly fired bricks

As shown in Figure 8, using freshly-fired brick fragments with a bed depth of 7,62 cm, 47,62 % of the fluoride was removed in the first 3 h, and 50,59 % was removed in the next 3 h. Sixty percent was eliminated after 9 h, and 50 percent was removed after 12 h. At a bed depth of 15,24 cm, there was a modest reduction in pH from 0 to 6 h, i.e., from 5,8 to 5,6, followed by a rise to 6,1 after 6 h. In the first 3 h, 6 h, 9 h, and 12 h, the removal efficiencies were 50,90 %; 35,80 %; 59,60 %; and 42,86 %, respectively, at a depth of 15,24 cm. Thus, by increasing the depth, neither the fluoride removal efficiency nor the pH increased significantly. However, the optimal removal time was 12 h for a bed with a 15,24 cm depth.

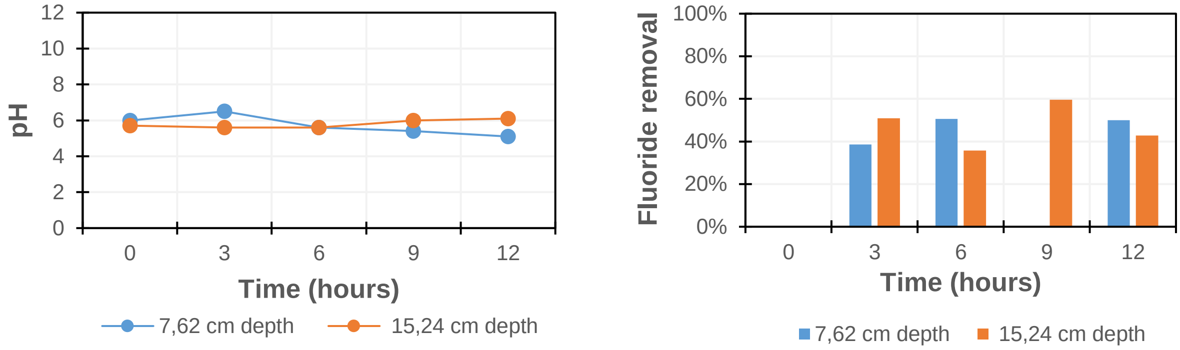

Figure 8. Change of pH and fluoride removal when freshly fired bricks were used as the absorbent

3.8 Fly ash

As shown in Figure 9, at a depth of 7,62 cm, 47,72 % of the fluoride was removed in the first 3 h, 42,57 % was removed after a contact time of 6 h, 32,75 % was removed after 9 h, and 17,94 % was removed after 12 h. When a fly ash (chullah) bed with a thickness of 15,24 cm was utilized, the pH value decreased from 3,5 to 3,3 from 0 to 6 h and then increased to 3,5 after 6 h. The amounts of fluoride eliminated in the first 3, 6, 9, and 12 h were 21,50 %; 7,96 %; 0,62 %; and 10,50 %, respectively. With increasing bed thickness and duration, the fluoride removal efficiency decreased, similar to the pH. However, the optimal removal time for fluoride was 3 h for a 7,62 cm depth.

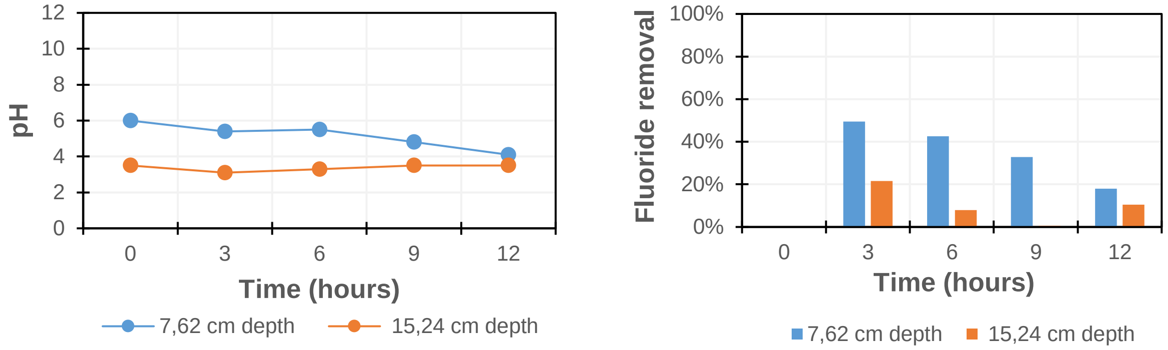

Figure 9. Changes in pH and fluoride removal when fly ash was used as the absorbent

3.9 Activated charcoal (rice husk)

As shown in Figure 10, using activated charcoal at a depth of 7,62 cm, 82,39 % of fluoride was removed in the first three hours, 96,00 % of fluoride was eliminated after 6 h of contact time, and after 9 and 12 h, the fluoride concentration was found to be less than 0,1 mg/L. During the first 3 h of utilizing activated charcoal at a depth of 15,24 cm, the pH rose from 4 to 5,5 and then dropped to 4. In the first 3 and 6 h, the removal efficiencies were 86,47 and 95,65 %, respectively, while after 9 and 12 h, the fluoride concentrations were below 0,1 mg/L.

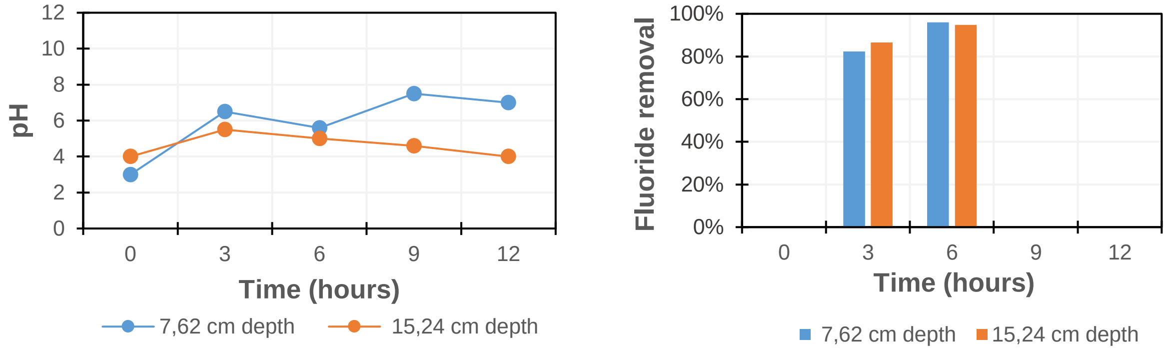

Figure 10. Changes in pH and fluoride removal when activated charcoal was used as the absorbent

Consequently, the fluoride removal efficiency was enhanced by increasing the bed thickness and duration. Increasing the duration without increasing the bed thickness neutralized the pH. However, the optimal fluoride removal time for fluoride was 6 h at a 7,62 cm depth.

4 Discussion of results

The percentage efficiency of fluoride concentration for all adsorbents decreased with time (Figure 11), and the removal efficiencies of marble chips, activated charcoal (rice husk), concrete, and freshly fired bricks were anticipated to encourage defluoridation of water, as they have satisfactory removal efficiencies. However, fly ash did not yield satisfactory results.

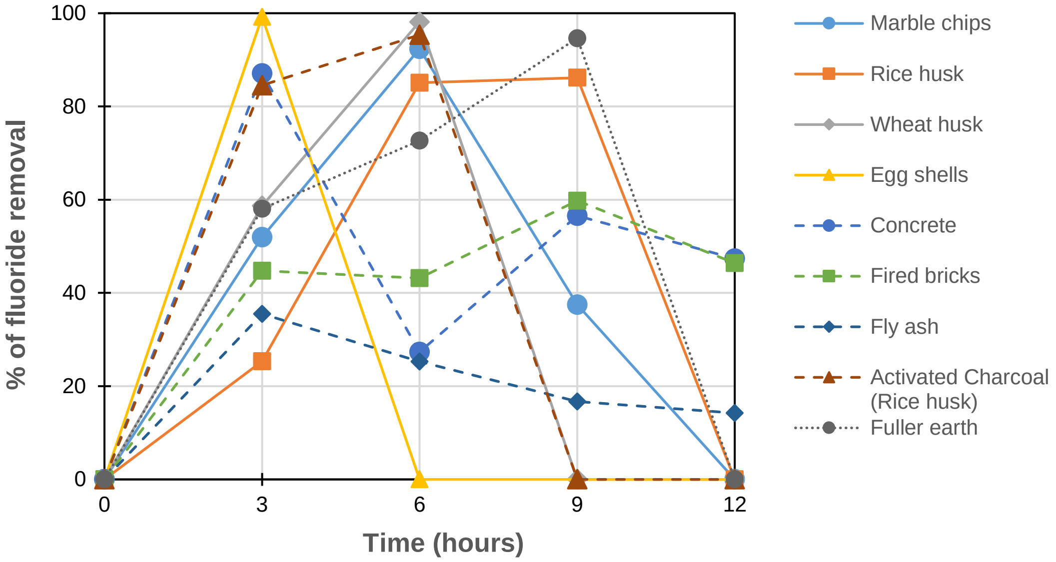

Figure 11. Interaction plot for the removal of fluoride at different contact hours using low-cost adsorbents

As shown in Figure 12, the fluoride concentration for all adsorbents decreased slightly as the thickness of the medium increased, except for fly ash, which increased the fluoride concentration. This may be due to the chemical characteristics of fly ash (55-60 % of the fluorine in the pulverized-coal-fired boiler is distributed in fly ash particles with a diameter of 74-104 microns [23]).

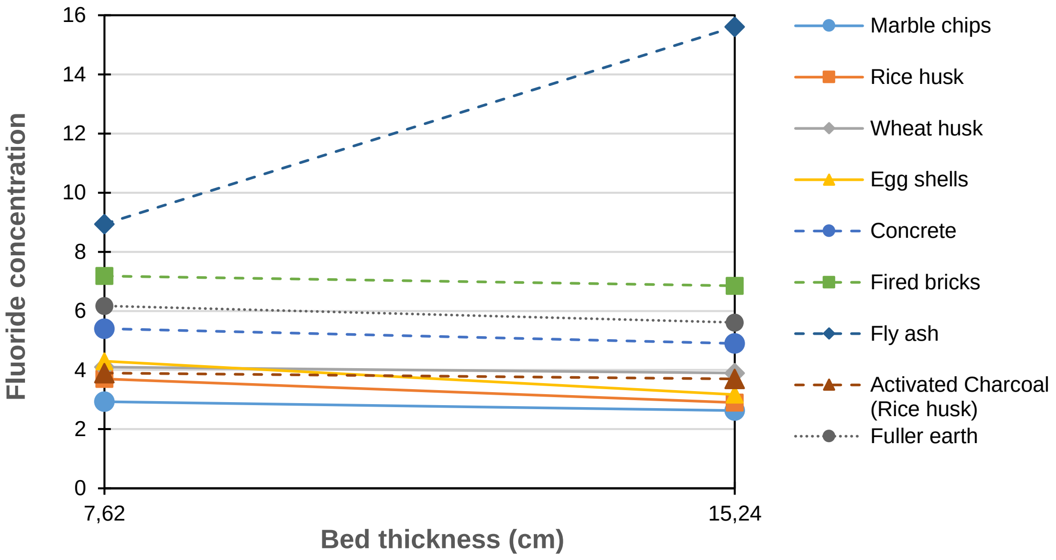

Figure 12. Graph of bed thickness vs. fluoride removal using low-cost adsorbents

As shown in Figure 13, the pH varied as time increased. It can be seen that the variation in pH depended on the material composition. These materials neutralised the pH of the water, except for the marble chips. Owing to the high percentage of calcium carbonate in the marble chips, which increased the pH, the solution became acidic.

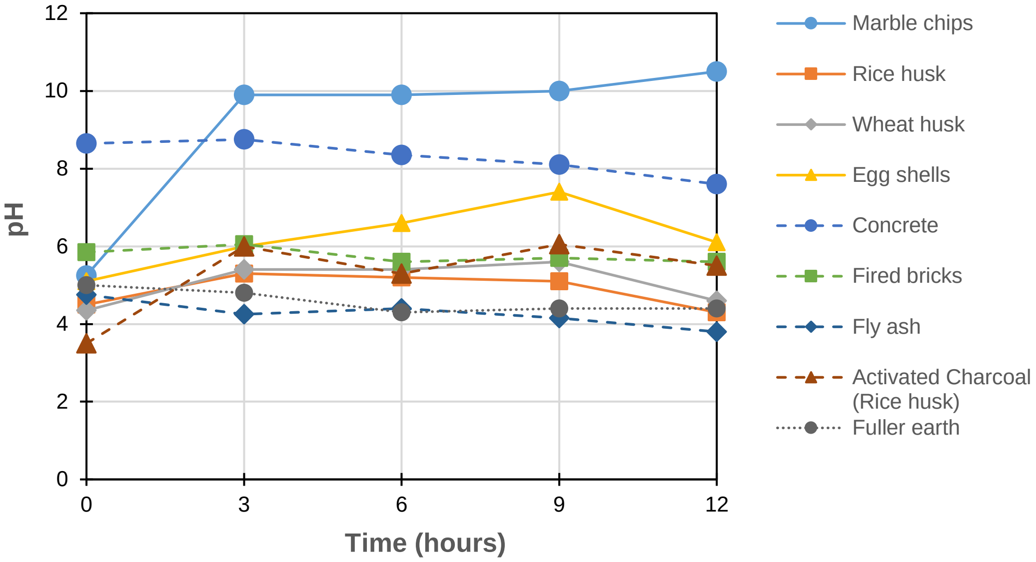

Figure 13. Interaction plot for pH when low-cost adsorbents are used

5 Correlation and regression analyses

The Pearson correlation coefficient (r) of fluoride concertation and bed thickness was 0,029; while the Pearson correlation coefficient (r) of fluoride concertation and pH was –0,290. The values indicate a weak correlation between these variables. However, the Pearson correlation coefficient (r) of fluoride concentration and time was –0,696; which suggests a strong and negative correlation between these variables; therefore, the fluoride concentration decreases as time increases.

As shown in Figure 14, there was a negative linear relationship between the contact time and fluoride concentration at different depths. The contact time and materials have a P-value of 0, which indicates that they are significantly related to the concentration of fluoride, whereas a P-value of 0,633; indicates that this variable is not related to fluoride concentration at a level of 0,05. This suggests that a regression model that uses only material and contact time is more appropriate.

Sample data are sufficient to reject the null hypothesis for the full population if the p-value for a given variable is less than the significance level, typically taken as 0,05, and if there is a non-zero correlation. At the population level, variations in independent variables influence the dependent variable. Coefficient p-values are typically used to determine whether to include the variables in the final model. A reduction in the fluoride concentration should be considered based on the results obtained. Using variables that are not statistically significant can reduce model accuracy. Therefore, the regression analysis with fluoride concentration versus time, material, and bed thickness with general results is presented in Table 2 and Figure 14.

Table 2. Regression analysis with fluoride concentration versus contact time, material, bed thickness

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	10	2419,38	241,94	18,73	0,000
Hours	1	1665,62	1665,62	128,97	0,000
Material	8	750,79	93,85	7,27	0,000
Bed Thickness	1	2,97	2,97	0,23	0,633

The R^2 value of this model was 86,91 %. This result suggests that contact time, material, and bed thickness were responsible for 86,91 % variance in the concentration of fluoride ions. As time increased, the fluoride concentration decreased; however, equilibrium was reached at a certain time limit, and a further reduction in fluoride ions was impossible.

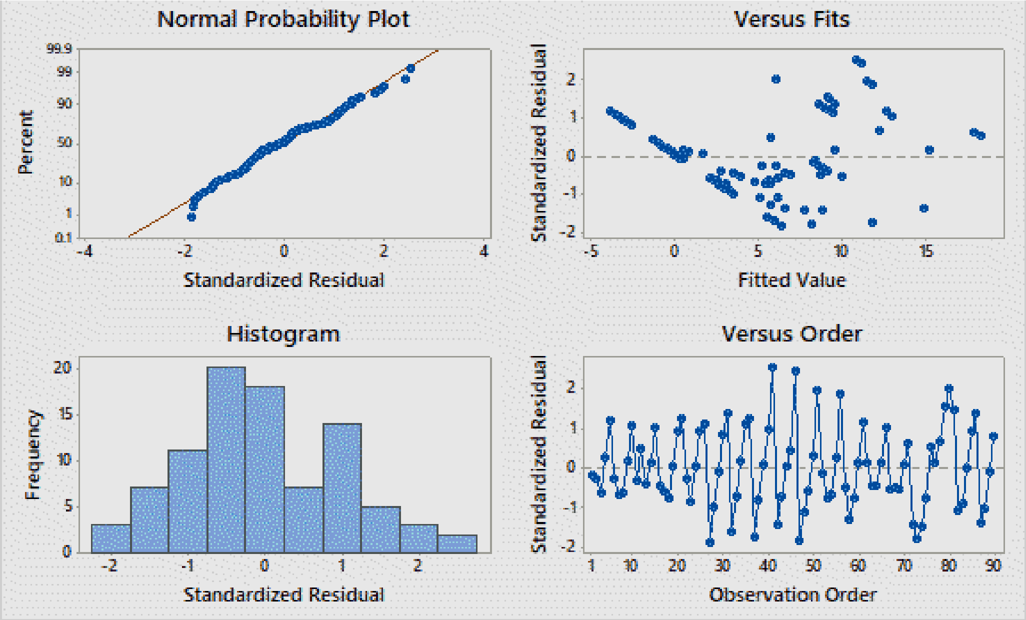

Figure 14. Regression analysis for fluoride concentration using low-cost adsorbents at different depths and time

6 Physical water quality parameters and cost efficiency of defluoridated water

The solute concentration gradient was strong, and all adsorbent sites were initially empty, which may have contributed to these fluctuations in the removal rate. Owing to the reduction in the number of adsorption sites, the rate of fluoride uptake by the adsorbent decreased dramatically. A decreased removal rate, especially near the end of the experiment, suggests that fluoride ions may have formed a monolayer on the outer surface of low-cost adsorbents and pore diffusion onto the inner surface of low-cost adsorbent particles through the film. As shown in Table 3, marble chips, activated charcoal (rice husk), concrete, and freshly fired bricks are expected to improve the physical characteristics of water because they do not impart any colour or odour to the water. Wheat husks, rice husks, eggshells, and fly ash are inadequate for improving physical water quality parameters.

Based on the results above, marble chips are considered the best for removing fluoride as they are cheaply available, can be used to obtain drinkable water, and are easy to handle. Moreover, wasted marble chips can be used in the manufacturing of tiles, floors, and many other construction processes. Additionally, increasing the bed thickness increases the fluoride removal efficiency because of the greater absorption capacity of the adsorbent. Owing to the presence of calcium carbonate, the pH was neutralized. Therefore, marble chips effectively treat highly acidic wastewater (industrial wastewater) and eliminate its corrosive properties. Activated charcoal (rice husk) also exhibited good efficiency in fluoride.

According to table 4 the cost per liter of water was 80,0 % less than marble chips, but its production requires proper techniques. The costs per liter of water of the bricks and concrete were 60,0 % and 93,3 %, respectively, less than that of marble chips. However, because of these materials' reduced fluoride removal efficiencies, these are not considered appropriate for defluoridation.

Table 3. Assessment of the physical water quality parameters of defluoridated water

No.	Materials	Colour	pH 6,5–8,5 (WHO)		Turbidity <5 NTU (WHO)		Remarks
			7,62 cm bed	15,24 cm bed	7,62 cm bed	15,24 cm bed	
1	Rice Husk	Yellowish	3,8	4,8	93,40	96,30	Further treatment is required for colour, turbidity, and pH
2	Marble Chips	Colourless	10,0	11,0	2,31	2,84	Further treatment is required for pH
3	Wheat Husk	Brownish	4,1	5,1	44,50	47,70	Further treatment is required for colour, turbidity, and pH
4	Egg Shells	Cloudiness	5,6	6,6	28,20	30,70	Further treatment is required for colour, turbidity, and pH
5	Fly Ash	Slightly Yellow	4,1	3,5	25,90	26,20	Further treatment is required for colour, turbidity, and pH
6	Freshly Fired Bricks	Colourless	5,1	6,1	4,90	5,79	Further treatment is required for pH and turbidity.
7	Concrete	Colourless	10,2	5,0	1,90	2,00	Further treatment is required for pH
8	Fuller Earth	Colourless	4,4	5,1	10,30	11,58	Further treatment is required for pH and turbidity.
9	Activated Charcoal (rice husk)	Colourless	7,0	4,0	1,50	1,50	Further treatment is required for pH.

Wheat husks, rice husks, egg shells, and fly ash are also cheap, and their costs per liter of water are 46,67 %; 86,67 %; 95,00 %; and 90,00 %, respectively, less than that of marble chips. However, the water obtained was not drinkable due to its odour and turbidity.

Table 4. Cost Estimation

Material	Units	Quantity of Material	Unit Price ($)	Cost ($)
Wheat Husk	10 kg	4	0,36	1,45
Bricks	1000 No.	24	45,45	1,09
Marble Chips	kg	4	0,70	2,72
Egg Shells	10 kg	3	0,45	0,14
Rice Husk	10 kg	4	0,09	0,36
Concrete	10 kg	4	0,09	0,18
Fly Ash	10 kg	6	0,09	0,27
Fuller Earth	kg	4	2,00	8,18
Activated Charcoal (Rice Husk)	kg	4	0,14	0,55

Wheat husks, rice husks, and eggshells are appropriate for the defluoridation and neutralization of the pH of wastewater; therefore, secondary treatment may be required to remove turbidity and odour. Cleaning eggshells before use is an effective and economical solution. Fuller earth (Multani Mitti) is the most expensive adsorbent, and it's cost per litre of water is 200 % higher than that of marble chips, but the water obtained after its use is drinkable.

7 Conclusions and recommendations

In this study, low-cost multiform materials were used for the defluoridation of aqueous solutions. The efficiency and cost of each adsorbent were also investigated. Accordingly, the following conclusions were drawn:

- Marble chips, activated charcoal (rice husk), concrete, and freshly fired bricks were considered encouraging materials for the defluoridation of water, as they have satisfactory removal efficiencies and do not impart any colour or odour to the water. Marble chips were considered paramount for fluoride removal as they cost less than 1 dollar/kg and do not affect water quality.
- Wheat husks, rice husks, eggshells, and fly ash are low-cost adsorbents, but the water quality is inadequate. Moreover, husks make the water turbid.
- The performance of the adsorbents depended on parameters such as contact time, depth of the adsorbent media, and pH. The removal capacity was amplified by changing the pH, but the adsorbent bed depth had a minor effect on fluoride removal. The major contributors to fluoride removal from water were contact time and adsorbent composition.
- Awareness about the effects of fluoride and defluoridation methods must be spread among the people living in the regions of Lahore, Multan, Bahawalpur, Shiekhupura, Kasur, Gujranwala, Mandi Baha Uddin, Sargodha, Gujrat, Jhelum, Ziarat, Mastung, Loralai, and KPK, where higher fluoride content is present in groundwater through different means, such as talks, printed and electronic media, and development of operative and economic fluoride removal adsorbents for use in domestic, community, or commercial units should be performed.
- Defluoridation may depend on the quality of the bricks and concrete in the defluoridation units and the grain sizes of the adsorbents. Locally available raw materials such as coconut shells, husks of coconut shells, sugar, phyllantus, and moringa oliefra can be used to determine fluoride removal efficiency.

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