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Removal of Fluoride and Nitrate from Drinking Water by Low-Cost Adsorbents

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Abstract

Contamination of drinking water by fluoride and nitrate has become a serious environmental and public Contamination of drinking water by fluoride and nitrate has emerged as a major environmental and public health issue, particularly in rural and semi-urban areas. Excessive fluoride concentration in water can cause dental and skeletal fluorosis, while elevated nitrate levels may lead to serious health problems such as methemoglobinemia and other water-borne diseases. The present study focuses on the removal of fluoride and nitrate from drinking water using low-cost adsorbents as an economical, efficient, and sustainable treatment method. Various locally available adsorbent materials, including activated carbon, agricultural waste-based media, and natural minerals, were investigated for their adsorption efficiency. The study was carried out under different operating conditions such as pH, contact time, adsorbent dosage, and initial contaminant concentration to determine the optimum treatment conditions. The effectiveness of the adsorbents was evaluated in terms of percentage removal and adsorption capacity. Experimental results showed a considerable reduction in fluoride and nitrate concentrations, indicating that low-cost adsorbents can serve as a promising alternative to conventional water treatment technologies. This approach is especially beneficial for resource-limited regions due to its affordability, ease of availability, and sustainability. The study concludes that the use of economical adsorbent materials is a feasible and practical solution for providing safe drinking water.

Keywords: Fluoride removal, Nitrate removal, Drinking water treatment, Low-cost adsorbents, Adsorption, Water purification,

1. Introduction

Safe and potable drinking water is one of the most essential requirements for human health and sustainable development. However, contamination of groundwater and surface water by dissolved ions such as fluoride (F^-) and nitrate (NO_3^-) has become a major environmental and public health issue in many parts of the world, especially in rural and semi-urban regions. Both contaminants commonly originate from natural geological formations as well as anthropogenic activities such as excessive fertilizer use, industrial discharge, sewage infiltration, and improper waste disposal.

Fluoride is a naturally occurring element commonly found in rocks and minerals such as fluorite, apatite, and cryolite. During weathering and leaching processes, fluoride dissolves into groundwater sources. In small concentrations, fluoride is beneficial for the development of teeth and bones. However, when its concentration exceeds the permissible limit of 1.5 mg/L recommended by the World Health Organization (WHO), it may lead to severe health problems such as dental fluorosis, skeletal fluorosis, bone deformities, and neurological disorders. Fluoride contamination of groundwater is a widespread issue in many developing countries and is especially prominent in arid and semi-arid regions.

Similarly, nitrate contamination in drinking water is also a serious concern. Nitrate mainly enters water sources through agricultural runoff, nitrogen-based fertilizers, animal waste, septic tanks, and industrial effluents. Excess nitrate in drinking water is hazardous to human health and may cause methemoglobinemia (blue baby syndrome) in infants, along with other health risks such as thyroid dysfunction and long-term chronic diseases. The presence of nitrate in groundwater has increased significantly due to intensive agricultural practices and population growth.

Various conventional treatment methods such as reverse osmosis, ion exchange, electro dialysis, chemical precipitation, and membrane filtration are available for the removal of fluoride and nitrate from water. Although these methods are effective, they often involve high capital cost, skilled operation, high energy consumption, and maintenance requirements, making them less suitable for economically weaker and rural communities.

Among the available treatment techniques, adsorption has emerged as one of the most promising and economical methods due to its simplicity, effectiveness, ease of operation, and low sludge generation. In recent years, the use of low-cost adsorbents derived from agricultural waste, natural minerals, industrial by-products, and locally available materials has gained considerable attention. Materials such as activated carbon, fly ash, rice husk ash, red mud, clay minerals, bio char, and other biomass-based adsorbents have shown significant potential for fluoride and nitrate removal.

The use of low-cost adsorbents offers several advantages including economic feasibility, local availability, environmental sustainability, and suitability for decentralized water treatment systems. This makes them particularly useful in rural areas where access to advanced water treatment facilities is limited.

Therefore, the present study focuses on the removal of fluoride and nitrate from drinking water using low-cost adsorbents, with the objective of evaluating their adsorption efficiency under varying operating conditions such as contact time, pH, adsorbent dosage, and initial contaminant concentration. The study aims to provide a sustainable and cost-effective solution for improving drinking water quality.

2. Materials and Methodology

2.1 Materials Used

The materials used in the present study consisted of water samples, low-cost adsorbent media, laboratory glassware, and analytical instruments required for water quality testing.

(a) Water Samples

Water samples containing fluoride and nitrate were collected from drinking water sources such as bore well water, groundwater, or prepared synthetic water samples in the laboratory.
For experimental consistency, synthetic water samples may be prepared by dissolving:

- **Sodium fluoride (Na F)** for fluoride
- **Potassium nitrate (KNO_3)** for nitrate

in distilled water to obtain the desired concentration.

Typical initial concentration:

- Fluoride = **2–10 mg/L**
- Nitrate = **20–100 mg/L**

These ranges are commonly studied in adsorption experiments.

2.2 Low-Cost Adsorbent Materials

Low-cost adsorbents selected for the study may include locally available and economical materials such as:

- activated carbon
- rice husk ash
- fly ash
- red soil / clay
- biochar
- neem leaves powder
- coconut shell carbon
- sawdust ash

Low-cost and bio-based adsorbents are widely used for fluoride removal because of their affordability and good adsorption capacity.

2.3 Chemicals and Reagents

The following chemicals were used:

- Sodium fluoride (NaF)
- Potassium nitrate (KNO_3)
- Hydrochloric acid (HCl)
- Sodium hydroxide (NaOH)
- Distilled water
- SPADNS reagent (for fluoride analysis)
- Nitrate testing reagent / UV spectrophotometric reagent

2.4 Equipment and Apparatus

The following apparatus were used:

- Beakers (250 mL / 500 mL)
- Conical flasks
- Measuring cylinders
- Filter paper
- Funnel
- Digital weighing balance
- pH meter
- Magnetic stirrer
- Jar test apparatus / orbital shaker
- Spectrophotometer
- fluoride meter / ion meter (if available)

Analytical testing such as pH and concentration measurement is generally performed using standard laboratory instruments.

2.5 Methodology

2.5.1 Preparation of Adsorbent

The selected adsorbent was first washed with distilled water to remove dust and impurities.
It was then:

- dried in sunlight or hot air oven at **105°C**
- crushed into fine powder
- sieved using **300–600 micron sieve**
- stored in airtight container

A typical adsorbent preparation workflow is shown below.
This preparation approach is standard in adsorption studies.

2.5.2 Batch Adsorption Experiment

Batch adsorption experiments were carried out to determine removal efficiency.
Procedure

1. Take **100 mL** contaminated water sample in a conical flask.
2. Add known dosage of adsorbent:
   0.5 g, 1 g, 1.5 g, 2 g
3. Adjust pH using HCl / NaOH.
4. Keep on magnetic stirrer at **150 rpm**
5. Allow contact time:
   30, 60, 90, 120 min
6. Filter sample using Whatman filter paper
7. Analyze final fluoride and nitrate concentration

Batch studies with pH, contact time, and adsorbent dose are the standard methodology for such papers.

2.5.3 Parameters Studied

The following parameters were varied:

- **pH:** 4, 6, 7, 8
- **contact time:** 30–120 min
- **adsorbent dosage:** 0.5–2 g
- **initial concentration:** different levels
- **stirring speed:** 100–150 rpm

These variables strongly affect adsorption performance.

2.5.4 Calculation of Removal Efficiency

The percentage removal was calculated by:

$$Removal\ Efficiency\ (\%) = \frac{(Ci - Cf)}{Ci} * 100$$

Where: (Co) = initial concentration (mg/L)
(Cf) = final concentration (mg/L)

3. Result and Discussions

Table 1: Table Effect of Adsorbent Dosage on Fluoride and Nitrate Removal

Adsorbent Dosage (g/100 mL)	Final Fluoride Concentration (mg/L)	Fluoride Removal (%)	Final Nitrate Concentration (mg/L)	Nitrate Removal (%)
0.5	2.4	52	23.4	48
1.0	1.5	70	15.3	66
1.5	0.9	82	11.3	75
2.0	0.55	89	8.1	82
2.5	0.45	91	7.2	84

The above data is pictured in the next graph.

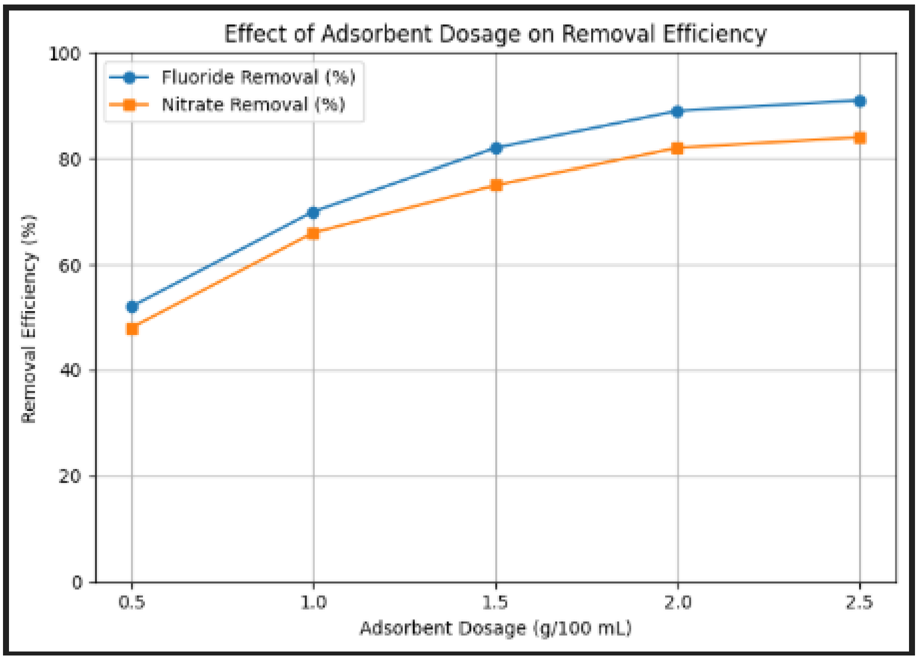

Figure 1: Effect of Adsorbent Dosage on Removal Efficiency

It is observed that removal efficiency increases with increase in adsorbent dosage due to greater availability of active adsorption sites.

4. Conclusion

The present study demonstrates that low-cost adsorbents are effective for the removal of fluoride and nitrate from drinking water. The experimental results showed that the adsorption efficiency increased with increase in adsorbent dosage, indicating the direct influence of available active surface sites on contaminant removal.

From the observed data, when the adsorbent dosage was increased from 0.5 g/100 mL to 2.5 g/100 mL**,** the fluoride removal efficiency increased from 52% to 91%**,** while nitrate removal increased from 48% to 84%**.** Simultaneously, the final fluoride concentration was reduced from 2.4 mg/L to 0.45 mg/L, and the nitrate concentration decreased from 23.4 mg/L to 7.2 mg/L**.**

The optimum adsorbent dosage was found to be 2.5 g/100 mL**,** at which maximum removal was achieved. The results clearly indicate that the selected low-cost adsorbent has strong adsorption potential and can be considered as an economical and sustainable treatment option for drinking water purification. Therefore, the study concludes that the use of low-cost adsorbents offers a cost-effective, eco-friendly, and practical solution**,** particularly for rural and resource-limited areas where access to advanced treatment technologies is limited. The method can be effectively applied for improving drinking water quality and reducing health risks associated with excessive fluoride and nitrate contamination.

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