Research Article

Investigation on Efficient Removal of Fluoride from Ground Water Using Activated Carbon Adsorbents

Naga Dheeraj Kumar Reddy Chukka,1 P. Gomathi Nagajothi,2 L. Natrayan,3 Yeddula Bharath Simha Reddy,4 Dhinakaran Veeman,5 Pravin P. Patil,6 and Subash Thanappan7

1Department of Civil Engineering, Aditya College of Engineering and Technology, Surampalem, Affiliated to Jawaharlal Nehru Technological University Kakinada, Kakinada, East Godavari District, India
2Department of Civil Engineering, Dr. M G R Educational and Research Institute, Maduravoyal, Chennai, 600095 Tamil Nadu, India
3Department of Mechanical Engineering, Saveetha School of Engineering, SIMATS, Chennai, 602105 Tamil Nadu, India
4School of Civil Engineering, REVA University, Bengaluru, India
5Centre for Additive Manufacturing, Chennai Institute of Technology, Chennai, 600069 Tamil Nadu, India
6Department of Mechanical Engineering, Graphic Era Deemed to Be University, Bell Road, Clement Town, 248002 Dehradun, Uttarakhand, India
7Department of Civil Engineering, Ambo University, Ambo, Ethiopia

Correspondence should be addressed to L. Natrayan; natrayan07@gmail.com and Subash Thanappan; thanappansubash@gmail.com

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Groundwater seems to be the most significant natural source of potable water for millions of individuals. Fluoride pollution in groundwater is a big problem in Tamil Nadu’s Dharmapuri area. According to a survey done in a school in the Dharmapuri area, dental and skeletal fluoroses afflict almost 75% of school kids. There is no proven or recommended cost-effective strategy for lowering fluoride levels in the home. This study proposes cost-effective and efficient natural treatment approaches for lowering fluoride levels. In this experiment, fluorides in groundwater are eliminated to a suitable extent utilizing natural adsorbents. Neem stem charcoal (activated carbon), neem leaves powder, dry coconut husk, coconut shell charcoal (activated carbon), and rice husk powder are natural adsorbents. The adsorbents were utilized at different concentrations until the best concentration was found. The ideal concentration removes the bulk of fluoride from groundwater and delivers adequate treatment. People could adopt this cost-effective procedure because just a few components are enough. As per the Bureau of Indian Standards, the concentration should not exceed 1.5 ppm, and it should not be lesser than 1 ppm; keeping this in mind, the neem stem charcoal which has higher efficiency in removing fluoride can be used in extensive environments, but in this selected place, it reduces the concentration even below 1 ppm, which relays below the standard level. As a result, adopting these procedures helps prevent dental and skeletal fluoroses, which is common among young people.

1. Introduction

Most people depend on groundwater for drinking and domestic purposes. In the last few decades, we observed that groundwater has been polluted by human activities in many countries, causing groundwater contamination [1]. There are fewer effective methods, and they cannot be accessible for individual dwellers to treat the excessive fluoride and other heavy metals available in groundwater [2]. This study ensures an economical and efficient method of removing the contamination as we are aware of fluoride, which plays a vital role in contamination and produces health issues in humans. The
The important reason for contamination of fluoride in groundwater is geological and anthropogenic activities. World Health Organization (WHO) has provided some guidelines for safe drinking water [3] with some permissible limits for fluoride contamination; it is 1.5 mg/L, the highest range. Skeletal and dental fluoroses, bone fracture risk, immune deficiency, and cancer are consequences of fluoride on public health [4]. The pollutants have been classified into organic and inorganic compounds for their removal as adsorbates by activated carbons. In general, organic compounds are nonpolar or slightly polar and therefore require oxygen-free activated carbons, devoid of polar surface groups, for their removal.

On the other hand, inorganic compounds are generally polar, so these will be adsorbed preferably by activated carbons associated with polar surface chemical groups. The acidic groups on the activated carbon surface dissociate into anionic groups in the high pH range. These anionic groups depress the adsorption of anionic compounds by electrostatic repulsion and promote the adsorption of cationic compounds by electrostatic attraction. Fluorosis affects almost 1.1 crore individuals in 160 districts across 16 states in India [5], with various levels between 1.5 ppm and 16 ppm. Fluoride deposition over the surface of bones and cartilage is the cause of fluorosis. Metabolic abnormalities, discoloured teeth and dental cavities, rigid joints, curved skeletal anatomy, and even paralysis have all been reported [6]. Scientists and researchers from the University of Bordeaux, France, have surveyed 3578 people and concluded that if the range of fluoride exceeds 1.8 ppm in drinking water, aged people above 65 years are affected with hip fractures. Specialists from Glasgow University discovered a significant reduction in white blood cells in fluorosis patients. Immunity deteriorated, and major illnesses resulted. Also, it causes the respiratory system, liver, digestive system, kidneys, excretory system, and enzyme disintegration to malfunction [7].

Non-skeletal fluorosis has several important consequences. The fluoride concentration in groundwater ranges in Dharmapuri and Salem districts, followed by Madurai, Dindugal, Trichy, Coimbatore, and Thanjavur. Scientists from the University of Bordeaux, France, surveyed 3578 people and concluded that if the range of fluoride exceeds 1.8 ppm in drinking water, aged people above 65 years are affected with hip fractures. Scientists from Glasgow University discovered a significant reduction in white blood cells in fluorosis patients. Immunity deteriorated, and major illnesses resulted. Also, it causes the respiratory system, liver, digestive system, kidneys, excretory system, and enzyme disintegration to malfunction [7].

**Figure 1:** Curve of the concentration and absorbance.

**Figure 2:** Neem powder adsorbent with initial fluoride concentration 2 ppm and 4 ppm.

**Figure 3:** Rice husk powder adsorbent with initial fluoride concentration 2 ppm and 4 ppm.
Chidambaram, and Coimbatore districts. Tirunelveli, Pudukkottai, and Remand districts in Tamil Nadu. 75% of students and kids have dental fluorosis [8]. Many people were affected by dental & skeletal fluorosis which led them to mottling teeth, osteosclerosis in the pelvis, chronic joint pain, and vertebral column [9]. Dental fluorosis is detected in various forms like discoloring, blackening, and chalk white teeth, which expose the exposure to fluoride in the growing stage of teeth in children [10]. The organic pollutants present in water constitute various organic compounds such as cationic and anionic organic compounds, nitro compounds, phenols, organic acids, amino compounds, halomethanes, pesticides, and dyes. These effects were more severe with a duct above 35 [11]. Defluorination may help to reduce the fluoride content in some countries. In developing and underdeveloped countries, the people and NGOs depend on bioadsorbents [12].

This study aims to provide purified drinking water for the locality, remove fluoride using materials that are available in nature, determine the effective natural adsorbent, and determine the optimum concentration of adsorbent for the effective removal of fluoride.

2. Evolution of Work

Vijay et al. conducted an in-depth survey in Pennagaram in four schools having 660 students from 5 to 13 age in January 2016; dental fluorosis affects more than 75% of people. This study shows an increasing tendency of this disease, common among the 10-12 age group students with above the WHO level 1.5 ppm [13]. Amarnath et al. carried out a study in the Dharmapuri district with a comprehensive study from the age of 2 to 25 years, which they were affected with skeletal mottling [14]. Sivarajasekar et al. surveyed Salem, Tamil Nadu had a specific study with 970 students including 630 boys and remaining girl students and found 36% of them were affected with dental decay [15]. Gayathri et al. compared various materials for the removal of fluoride; their investigation had some experimental works which expensive and safe methods for removing fluoride [16]. Gautam and Singh have prepared activated carbon materials using neem leaves and peepal leaves as adsorbents; they found a removal efficiency of six adsorbents and found activated neem is more efficient [17].

Bharali and Bhattacharyya carried out the experiments and concluded a few important results. The natural bioadsorbents available in and around the places have more efficient removal of fluoride and are more effective than other sophisticated methods. They tried treated neem and mango leaf powder with various concentrations and contact timings. Results gave a practical optimum value in removal efficiency within the 2.0 and 8.0 pH limits [18]. Hokkanen et al. compared various inorganics, organic, and natural adsorbents from various studies and found better materials. The environment, contamination, industrial effluent, natural water flow under the ground, water and soil pH level, temperature, and human activities mostly affect fluoride contamination. Metal ores and bioadsorbents have a natural capacity to observe fluoride with some certain limitations [19]. Islamuddin et al. studied various technologies to remove fluoride in the groundwater. In this paper, the coconut husk is used for defluoridation as a natural adsorbent, and it is analyzed that 86% of fluoride removal is possible. So the coconut husk is cheaper for the removal of fluoride in water; it has 86% efficiency of removal efficiency [20].
Comparison of removal efficiency of all adsorbents at 2ppm concentration

FIGURE 7: Comparison of removal efficiency of all adsorbents at 2 ppm.

Comparison of removal efficiency of all adsorbents at 2ppm concentration

FIGURE 8: Comparison of removal efficiency of all adsorbents at 4 ppm.
Karunarathne and Amarasinghe studied the percentage removal of fluoride content from groundwater using sugarcane bagasse. It gave an excellent fluoride removal efficiency of 86% from the drinking water of 5 g/l dose at 323 K temperature and was confirmed by the experiments [21]. Panchore et al. reviewed about few low-cost adsorbents like tea ash, punic, neem stem charcoal, bleaching powder, sawdust neem, pipal, activated neem leaves, bark of babool in removing fluoride in aqueous, and synthetic solutions; in these studies, the neem stem charcoal has the maximum rate of efficiency in removal of fluoride with 94% [22]. Ranjit et al. studied the fluoride removal from groundwater with the Modified bark of Terminalia Chebula (MTC). The results conclude that the Modified bark of Terminalia Chebula (MTC) has a good fluoride removal capacity with the optimum dose with an initial concentration of fluoride 2 g/L and 5 mg/L and 360 minutes as optimum contact time; in pH 6-8, the capacity of adsorption was peak [23]. Bandewar et al. had a brief study on granular activated carbon (GAC) from coconut shells and charcoal by continuous fixed-bed column in the defluoridation of water. Maximum fluoride removal of 72% in 4 ppm concentration and 4 ml/min flow, and the adsorbent dose is about 6 cm [24]. Bharali and Bhattacharyya used neem in the form of powder to remove fluoride from groundwater. The neem leaves were dried and powdered to be used as the bio adsorbent to remove fluoride. The effects of temperature, pH, and contact time were investigated, and fluoride removal efficiency at pH of 2 was 74.25% with a contact time of 300 minutes [25].

### Table 1: Fluoride removal efficiency in groundwater.

| Adsorbent            | Final fluoride concentration (ppm) | Removal efficiency (%) |
|----------------------|-----------------------------------|------------------------|
| Neem powder          | 0.96                              | 44.18                  |
| Rice husk powder     | 0.61                              | 64.53                  |
| Coconut husk         | 0.3                               | 82.55                  |

### Table 2: Removal efficiency comparison between stock solution and groundwater.

| Adsorbent                 | Removal efficiency (%) |          |
|---------------------------|------------------------|----------|
|                          | Stock solution | Groundwater |
| Neem powder               | 46.50               | 44.18     |
| Rice husk powder          | 66.00               | 64.53     |
| Coconut husk              | 85.00               | 82.55     |
| Coconut shell charcoal    | 69.50               | 68.02     |
| Neem stem charcoal        | 94.00               | 91.27     |

3. Materials and Methods

In this study, local agricultural waste products and their by-products were estimated and cross-verified for their availability, reducing the raw material cost and easy accessibility. In this case, neem, mango, banana, sugarcane, jack fruit, cashew, rice, paddy, cereals, coconut, palm, wheat, sunflower, eucalyptus, and many more agri products and their details were collected and analyzed. In these products, we found that the neem, rice, and coconut plants are in more quantity than others, giving a continuous supply of by-products and waste products throughout the year [26]. We gave more importance to the sustainability of the environment; in any case, we should not recommend growing or importing new organic materials outside the Dharmapuri district and its surroundings so that we are specific in the selection of materials [27]. This selected material has a huge quantity of by-products used for other purposes. So, we preferred this for our study.

3.1. Fluoride Stock Solution. The project uses 2 ppm-10 ppm stock solutions to find the optimum material. The stock solutions were prepared as per the procedure for 10 ppm, 4 ppm, and 2 ppm.

3.2. Preparation of Adsorbents. The adsorbents are prepared as per the procedure; they are in charcoal form and powder form.

3.3. Reagents. Reagents were prepared and used; they are SPADNS, zirconyl acid, and acid zirconyl-SPADNS reagent.

3.4. Standard Curve Preparation. Standard fluoride solution is prepared between 0 and 1.40 mg/L. By adding 50 ml of distilled water with standard fluoride solution, 10 ml of acid-zirconyl and SPADNS was mixed and taken in the pipette. Well stirring is done to avoid the contamination of two different solutions. A photometer is used to find the measurements of the solution by setting it as per the procedure. The readings absorbed for a sample are compared with the standard solution [28]. Figure 1 shows the curve of the concentration and absorbance.

4. Experiment Using Stock Solution

The prepared adsorbents are used in the following concentrations with the respective contact time. Fluoride concentration taken as constant 2 ppm, 4 ppm, and adsorbent concentration of 0.2, 0.4, 0.6, 0.8, and 1.0 g for 100 ml sample for 10, 30, and 60 minutes as contact time period.

4.1. Neem Powder Adsorbent. The neem powder adsorbent reaches a maximum efficiency of 46.5% at the adsorbent concentration 1 g/100 ml at 1 hour contact time. The neem powder adsorbent reaches a maximum efficiency of 41.25% at the adsorbent concentration 1 g/100 ml at 1 hour contact time [29].

Figure 2 is plotted for various adsorbent concentrations at 1 hour contact time. It can be seen that decreasing in removal efficiency with the rise in the concentration of fluoride.

4.2. Rice Husk Powder Adsorbent. The rice husk powder adsorbent reaches a maximum efficiency of 66% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time. It can be seen that the removal efficiency remains constant from 0.6 g/100 ml adsorbent concentration [30]. The rice husk powder adsorbent reaches a maximum efficiency
of 63.5% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time. It can be seen that the removal efficiency remains constant from 0.6 g/100 ml adsorbent concentration [31].

Figure 3 is plotted for rice husk powder adsorbent with initial fluoride concentration 2 ppm and 4 ppm. It can be seen that decreasing removal efficiency is a rise in the concentration of fluoride [32].

4.3. Coconut Husk Adsorbent. The coconut husk adsorbent reaches a maximum efficiency of 85% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time. The coconut husk adsorbent reaches a maximum efficiency of 81% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time [33]. The coconut husk adsorbent touches a maximum efficiency of 81% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time [34]. Figure 4 is plotted for various adsorbent concentration at 1 hour contact time for coconut husk adsorbent with initial fluoride concentrations of 2 ppm and 4 ppm [35]. It can be seen that there is a decrease in efficiency with the increase in concentration of fluoride.

4.4. Coconut Shell Charcoal Adsorbent. The coconut shell charcoal adsorbent reaches a maximum efficiency of 69.5% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time [36]. The coconut shell charcoal adsorbent reaches a maximum efficiency of 63.75% at the adsorbent concentration of 1 g/100 ml at 1 hour contact time [37]. Figure 5 is plotted for various adsorbent concentrations at 1 hour contact time for coconut shell charcoal adsorbent initial fluoride concentration 2 PPM and 4 PPM. It shows a decrease in efficiency with the fluoride concentration increase [38].

4.5. Neem Stem Charcoal Adsorbent. The neem stem charcoal adsorbent reaches a maximum efficiency of 94% at the adsorbent concentration 1 g/100 ml at 1 hour contact time. The coconut shell charcoal adsorbent reaches a maximum efficiency of 91% at the adsorbent concentration 1 g/100 ml at 1 hour contact time [39].
Figure 6 is plotted for various adsorbent concentrations at 1 hour contact time for neem stem charcoal adsorbent initial fluoride concentration 2 PPM and 4 PPM. It shows a decrease in efficiency concerning concentration increase [40]. Neem stem charcoal has the highest removal efficiency, and neem powder has the lowest [41].

Figure 7 is plotted for all adsorbents at 1 hour contact time and a comparison of all adsorbents’ removal efficiency at 2 ppm. As we can see, neem stem charcoal has the highest removal efficiency, and neem powder has the lowest removal efficiency [42].

Figure 8 is plotted for all adsorbents at 1 hour contact time and a comparison of all adsorbents’ removal efficiency at 4 ppm. As we can see, neem stem charcoal has the highest removal efficiency, and neem powder has the lowest removal efficiency [43].

5. Experiments Using Groundwater Sample

Groundwater sample location: Pennagaram City, Dharmapuri District, Tamil Nadu [44]; borewell/open wells have used to collect samples, their initial fluoride concentration is 1.72 ppm, turbidity is 1NTU and pH 6.9 [45].

5.1. Testing of Water for Fluoride from Groundwater after Using Adsorbents. The testing of fluoride removal from water is carried out using an adsorbent concentration of 1 g/100 ml and a contact time of 1 hour shown in Table 1.

Table 2 shows the comparison of the removal efficiency of various adsorbents in stock solution and groundwater.

Table 2 exposed the comparison graph of removal efficiency between stock solution and groundwater. Figure 9 identified that the removal efficiency of fluoride in groundwater is less than the stock solution. This is due to the other contaminants present in the water collected [46]. Therefore, according to the required final fluoride concentration, the adsorbent concentration and contact time are selected accordingly for the various adsorbents [47].

5.2. Comparison Results. Organic materials have the property of absorbing contaminations. Still, the efficiency and contact time may not be predictable [48], so we have to prepare the organic materials into an activated carbon source that can actively adsorb the contaminations in limited contact timings [49]. Hence, this study picks some selective natural materials which are plenty available as organic carbon source as a raw material with a small preparation in a controlled temperature to activate the carbon source as activated carbon; this activation accelerates the adsorbent capacity of the carbon source in short time duration so that contact time is comparably lesser than normal organic adsorbents [50]. The adsorbents proved to remove fluoride at a very high level with groundwater. The removal efficiency of all adsorbents kept increasing except for rice husk [51]. Table 3 shows the adsorbent concentration and contact time for treating groundwater. Rice husk and coconut husk have an average removal efficiency in the four materials, neem stem charcoal has the highest efficiency, and neem powder has the lowest efficiency.

6. Conclusion

The groundwater from the Dharmapuri district had a fluoride concentration of 1.72 ppm. As per the Bureau of Indian Standards, the concentration should not exceed 1.5 ppm, and it should not be less than 1 ppm; keeping this in mind, the neem stem charcoal which has higher efficiency in removing fluoride can be used in extensive environments, but in this selected place, it reduces the concentration even below 1 ppm, which relay below the standard level. The other adsorbents can be used with concentration and contact time ensuring a safer groundwater consumption range.

This study considers a viable practice for removing contamination which should be easy to work and materialize with ease; so, just adopting a simple practice of stirring the carbon adsorbent material with contaminated water can be achieved, as these materials are available in and around the villages and small towns of Dharmapuri district, which can be easily accessible and available in affordable price, people can utilize this method and material extensively.

Data Availability

The data used to support the findings of this study are included within the article. Should further data or information be required, these are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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References

[1] C. H. Jeong, "Effect of land use and urbanization on hydrochemistry and contamination of groundwater from Taejon area, Korea," Journal of Hydrology, vol. 253, no. 1-4, pp. 194–210, 2001.
[2] E. Vetrimurugan, K. Brindha, L. Elango, and O. M. Ndwandwe, "Human exposure risk to heavy metals through groundwater used for drinking in an intensively irrigated river delta," Applied Water Science, vol. 7, no. 6, pp. 3267–3280, 2017.
[3] H. N. Kim, W. X. Ren, J. S. Kim, and J. Yoon, "Fluorescent and colorimetric sensors for detection of lead, cadmium, and mercury ions," Chemical Society Reviews, vol. 41, no. 8, pp. 3210–3244, 2012.
[4] P. T. C. Harrison, "Fluoride in water: a UK perspective," Journal of Fluorine Chemistry, vol. 126, no. 11-12, pp. 1448–1456, 2005.
[5] B. Ray, "Tracing the progress of drinking water security in rural India through policy initiatives," Risk, Hazards & Crisis in Public Policy, vol. 7, no. 1, pp. 25–51, 2016.
[6] N. D. K. R. Chukka, L. Natrayan, and W. D. Mammo, “Seismic fragility and life cycle cost analysis of reinforced concrete structures with a hybrid damper,” *Advances in Civil Engineering*, Article ID 2021, 2021.

[7] S. Praburanganathan, N. Sudharsan, Y. B. S. Reddy, N. D. K. R. Chukka, L. Natrayan, and P. Paramasivam, “Force-deformation study on glass fiber reinforced concrete slab incorporating waste paper,” *Advances in Civil Engineering*, vol. 2022, Article ID 5343128, 10 pages, 2022.

[8] J. K. Baskaradoss, R. B. Clement, and A. Narayanan, “Prevalence of dental fluorosis and associated risk factors in 11-15 year old school children of Kanyakumari District, Tamilnadu, India: a cross sectional survey,” *Indian Journal of Dental Research*, vol. 19, no. 4, pp. 297–303, 2008.

[9] S. Ayyob and A. K. Gupta, “Fluoride in drinking water: a review on the status and stress effects,” *Critical Reviews in Environmental Science and Technology*, vol. 36, no. 6, pp. 433–487, 2006.

[10] J. P. Yadav, S. Lata, S. K. Kataria, and S. Kumar, “Fluoride distribution in groundwater and survey of dental fluorosis among school children in the villages of the Jhajjar District of Haryana, India,” *India. Environmental geochemistry and health*, vol. 31, no. 4, pp. 431–438, 2009.

[11] C. C. Martins, S. M. Paiva, Y. B. Lima-Arsati, M. L. Ramos-Jorge, and J. A. Cury, “Prospective study of the association between fluoride intake and dental fluorosis in permanent teeth,” *Caries Research*, vol. 42, no. 2, pp. 125–133, 2008.

[12] V. Kimambo, P. Bhattacharyya, F. Mtalo, J. Mtamba, and A. Ahmad, “Fluoride occurrence in groundwater systems at global scale and status of defluoridation - state of the art,” *Groundwater for Sustainable Development*, vol. 9, article 100223, 2019.

[13] K. Vijay, S. M. Mazhar, and N. Khan, “Analysis of fluoride level in groundwater and fluoride survey among school children in Pennagaram block, Dharmapuri district, TN India,” *International Journal Sciences and Applied Research*, vol. 4, pp. 85–90, 2017.

[14] D. Joshua Amarnath, V. E. NethajiMariappan, M. Anne Beaula, and N. Vadhivel, “Evaluating fluoride contamination in groundwater of Dharmapuri District in Tamil Nadu,” *Journal of Chemical and Pharmaceutical Sciences*, vol. 8, no. 1, pp. 420–429, 2015.

[15] N. Sivarajasekar, T. Paramasivan, S. Muthusaranavanan, and P. Muthukumarana, “Defluoridation of water using adsorbents-a concise review,” *Journal of Environment and Biotechnology*, vol. 6, no. 1, pp. 186–198, 2017.

[16] G. Gayathri, B. C. Kumar Raj, D. S. Reddy, and M. Beulah, “Defluoridation of ground water using low-cost adsorbents,” *International Journal of Earth Sciences and Engineering*, vol. 10, pp. 967–972, 2017.

[17] N. Gautam and R. K. Singh, “Removal of fluoride from groundwater by thermally activated neem (Azadiractica indica) and peepal (Ficus religiosa) leaves carbon adsorbents,” *World Journal of Pharmacy and Pharmaceutical Sciences*, vol. 6, no. 7, pp. 1050–1057, 2017.

[18] R. K. Bharali and K. G. Bhattacharyya, “Biosorption of fluoride on Neem ( _Azadirachta indica_ ) leaf powder,” *Journal of Environmental Chemical Engineering*, vol. 3, no. 2, pp. 662–669, 2015.

[19] S. Hokkanen, A. Bhatnagar, and M. Sillanpää, “A review on modification methods to cellulose-based adsorbents to improve adsorption capacity,” *Water Research*, vol. 91, pp. 156–173, 2016.

[20] R. Islamuddin, K. Gautam, and F. Shaista, “Removal of fluoride from drinking water by coconut husk as natural adsorbent,” *International Journal of Engineering Sciences & Research Technology*, vol. 50, pp. 84–86, 2016.

[21] H. D. S. K. Karunaratne and B. W. M. P. K. Amarasinghe, “Fixed bed adsorption column studies for the removal of aqueous phenol from activated carbon prepared from sugarcane bagasse,” *Energy Procedia*, vol. 34, pp. 83–90, 2013.

[22] K. Panchore, S. Sharma, A. Sharma, and S. Verma, “Defluoridation of contaminated water by using low-cost adsorbents: a review,” *International Journal of Advanced Science and Research*, vol. 1, no. 6, pp. 28–32, 2016.

[23] R. N. Patil, P. B. Nagarnail, and D. K. Agarwal, “Removal of fluoride from groundwater by using modified bark of Terminalia chebula,” *International Journal of Civil Engineering and Technology*, vol. 7, no. 6, pp. 21–30, 2016.

[24] S. Bandewar, S. Mane, and S. Tirthakar, “Removal of fluoride from drinking water by using low cost adsorbent,” *International Journal of Research in Engineering and Technology*, vol. 4, no. 4, pp. 349–351, 2015.

[25] A. Darshan, N. Giridas, R. Bhojwani et al., “Energy Audit of a Residential Building to Reduce Energy Cost and Carbon Footprint for Sustainable Development with Renewable Energy Sources,” *Advances in Civil Engineering*, vol. 2022, article 4400874, p. 10, 2022.

[26] A. B. H. Bejaixin and G. Paulraj, “Experimental investigation of vibration intensities of CNC machining centre by microphone signals with the effect of TiN/epoxy coated tool holder,” *Journal of Mechanical Science and Technology*, vol. 33, no. 3, pp. 1321–1331, 2019.

[27] S. Ghorai and K. K. Pant, “Investigations on the column performance of fluoride adsorption by activated alumina in a fixed-bed,” *Chemical Engineering Journal*, vol. 98, no. 1-2, pp. 165–173, 2004.

[28] Y. Devarajan, D. B. Munuswamy, B. T. Nalla, G. Choubey, R. Mishra, and S. Vellaiyan, “Experimental analysis of Sterculia foetida biodiesel and butanol blends as a renewable and eco-friendly fuel,” *Industrial Crops and Products*, vol. 178, article 114612, 2022.

[29] A. B. H. Bejaixin, G. Paulraj, and S. Aravind, “Influence of TiN/AlCrN electrode coatings on surface integrity, removal rates and machining time of EDM with optimized outcomes,” *Materials Today: Proceedings*, vol. 21, pp. 340–345, 2020.

[30] B. D. Gebrewold, P. Kijjanapanich, E. R. Rene, P. N. L. Lens, and A. P. Annachhatre, “Removal of fluoride from groundwater using chemically modified rice husk and corn cob activated carbon,” *Environmental Technology*, vol. 40, no. 22, pp. 2913–2927, 2019.

[31] D. Tang and G. Zhang, “Efficient removal of fluoride by hierarchical Ce-Fe bimetal oxides adsorbent: thermodynamics, kinetics and mechanism,” *Chemical Engineering Journal*, vol. 283, pp. 721–729, 2016.

[32] J. Wang, W. Liying, J. Li, D. Tang, and G. Zhang, “Simultaneous and efficient removal of fluoride and phosphate by Fe-La composite: adsorption kinetics and mechanism,” *Journal of Alloys and Compounds*, vol. 753, pp. 422–432, 2018.

[33] S. Vellaiyan, A. Subbiah, S. Kuppusamy, S. Subramanian, and Y. Devarajan, “Water in waste-derived oil emulsion fuel with cetane improver: formulation, characterization and its
optimalization for efficient and cleaner production,” Fuel Processing Technology, vol. 228, article 107141, 2022.

[34] S. Rajkumar, S. Murugesh, V. Sivasankar, A. Darchen, T. A. M. Msagati, and T. Chaabane, “Low-cost fluoride adsorbents prepared from a renewable biowaste: syntheses, characterization and modeling studies,” Arabian Journal of Chemistry, vol. 12, no. 8, pp. 3004–3017, 2019.

[35] G. Choubey, P. M. Yadav, Y. Devarajan, and W. Huang, “Numerical investigation on mixing improvement mechanism of transverse injection based scramjet combustor,” Acta Astronautica, vol. 188, pp. 426–437, 2021.

[36] B. D. Turner, P. Binning, and S. L. S. Stipp, “Fluoride removal by calcite: evidence for fluorate precipitation and surface adsorption,” Environmental Science & Technology, vol. 39, no. 24, pp. 9561–9568, 2005.

[37] A. Bhatnagar, E. Kumar, and M. Sillanpää, “Fluoride removal from water by adsorption—a review,” Chemical Engineering Journal, vol. 171, no. 3, pp. 811–840, 2011.

[38] A. Devaraj, Y. Devarajan, and I. Vinoth Kanna, “Investigation on emission pattern of biodiesel and Nano-particles,” International Journal of Ambient Energy, vol. 42, no. 10, pp. 1103–1107, 2021.

[39] D. Damodharan, K. Gopal, A. P. Sathiyagnanam, B. Rajesh Kumar, M. V. Depoures, and N. Mukilarasan, “Performance and emission study of a single cylinder diesel engine fuelled within-octanol/WPO with some modifications,” International Journal of Ambient Energy, vol. 42, no. 7, pp. 779–788, 2021.

[40] N. Tefera, Y. Mulualem, and J. Fito, “Adsorption of fluoride from aqueous solution and groundwater onto activated carbon of avocado seeds,” Water Conservation Science and Engineering, vol. 5, no. 3–4, pp. 187–197, 2020.

[41] A. Bovas Herbert Bejaxhin, G. Paulraj, G. Jayaparakash, and V. Vijayan, “Measurement of roughness on hardened D-3 steel and wear of coated tool inserts,” Transactions of the Institute of Measurement and Control, vol. 43, no. 3, pp. 528–536, 2021.

[42] Z. Jin, Y. Jia, K.-S. Zhang et al., “Effective removal of fluoride by porous MgO nanoparticles and its adsorption mechanism,” Journal of Alloys and Compounds, vol. 675, pp. 292–300, 2016.

[43] M. Gao, W. Wang, H. Yang, and B.-C. Ye, “Efficient removal of fluoride from aqueous solutions using 3D flower-like hierarchical zinc-magnesium-aluminum ternary oxide microspheres,” Chemical Engineering Journal, vol. 380, article 122459, 2020.

[44] Y. Devarajan, B. Nagappan, G. Subbiah, and E. Kariappan, “Experimental investigation on solar-powered ejector refrigeration system integrated with different concentrators,” Environmental Science and Pollution Research, vol. 28, no. 13, pp. 16298–16307, 2021.

[45] T. Sathish, K. Palani, L. Natrayan, A. Merneedi, M. V. De Pures, and D. K. Singaravelu, “Synthesis and characterization of polypropylene/ramie fiber with hemp fiber and coir fiber natural biopolymer composite for biomedical application,” International Journal of Polymer Science, vol. 2021, Article ID 2462873, 2021.

[46] D. B. Munuswamy, M. Yuvarajan Devarajan, N. Babu, and S. Ramalingam, “Experimental investigation on lowering the environmental hazards and improving the performance patterns of solar flat plate collectors by employing the internal longitudinal fins and nano additives,” Environmental Science and Pollution Research, vol. 27, no. 36, pp. 45390–45404, 2020.

[47] M. Talat, S. Mohan, V. Dixit, D. K. Singh, S. H. Hasan, and O. N. Srivastava, “Effective removal of fluoride from water by coconut husk activated carbon in fixed bed column: experimental and breakthrough curves analysis,” Groundwater for Sustainable Development, vol. 7, pp. 48–55, 2018.

[48] N. D. K. R. Chukka, A. Arivumangai, S. Kumar et al., “Environmental impact and carbon footprint assessment of sustainable buildings: an experimental investigation,” Adsorption Science & Technology, vol. 2022, article 8130180, p. 8, 2022.

[49] J. Zhou, W. Zhu, Y. Jie et al., “Highly selective and efficient removal of fluoride from ground water by layered Al-Zr-La tri-metal hydroxide,” Applied Surface Science, vol. 435, pp. 920–927, 2018.

[50] J. Zhou, Y. Liu, Y. Han, F. Jing, and J. Chen, “Bone-derived biochar and magnetic biochar for effective removal of fluoride in groundwater: effects of synthesis method and coexisting chromium,” Water Environment Research, vol. 91, no. 7, pp. 588–597, 2019.

[51] J. Wang, N. Chen, M. Li, and C. Feng, “Efficient removal of fluoride using polypyrrole-modified biochar derived from slow pyrolysis of pomelo peel: sorption capacity and mechanism,” Journal of Polymers and the Environment, vol. 26, no. 4, pp. 1559–1572, 2018.