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Advances in Low-Cost Defluoridation Techniques for Safe Drinking Water with respect to Innovations and Plant-Based Adsorbents

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ABSTRACT

Fluoride contamination in drinking water is a global health concern, particularly in rural and low-income communities, where high fluoride levels lead to dental and skeletal fluorosis, and potentially neurological and endocrine disorders. This paper reviews recent advancements in low-cost defluoridation methods that offer sustainable solutions for fluoride removal, particularly in resource-limited regions. It explores natural adsorbents such as biochar, clay, and plant-based materials like Moringa oleifera and coconut shells, which have shown promising results in reducing fluoride concentrations. Additionally, nanotechnology-based solutions, including nano-hydroxyapatite and modified zeolites, as well as membrane filtration techniques like reverse osmosis and forward osmosis, are discussed for their potential in enhancing defluoridation while remaining cost-effective. The paper further examines field applications and case studies from countries such as India, Kenya, and Bangladesh, highlighting the effectiveness of these low-cost technologies in real-world settings. Despite their promise, the paper acknowledges several challenges, including technical issues such as filter clogging and reduced efficiency, socio-economic barriers like affordability and cultural acceptance, and environmental concerns related to the disposal of used defluoridation materials. The study emphasizes the importance of continued innovation, community involvement, and the support of governmental and non-governmental organizations to overcome these barriers and ensure the widespread adoption of these technologies. By addressing fluoride contamination effectively and affordably, these methods can significantly improve public health in affected communities, ensuring access to safe drinking water for millions globally.

Keywords: Fluoride; Defluoridation; Biochar; Adsorption; Nanotechnology; Filtration; Contamination; Sustainability; Water purification

INTRODUCTION

Fluoride is a naturally occurring element found in varying concentrations in water sources, soil, and certain minerals. While low concentrations of fluoride are beneficial for dental health, excessive fluoride exposure, particularly through drinking water, can lead to serious health issues. Fluoride contamination in groundwater is a significant concern in many parts of the world, notably in regions where groundwater is the primary drinking water source and where the geological formation is rich in fluoride-bearing minerals. Countries such as India, China, parts of Africa, and Latin America report high levels of fluoride in groundwater due to geological factors as well as industrial pollution (Ayoob & Gupta, 2006; Fawell et al., 2006).

One of the most critical health impacts of high fluoride levels is dental fluorosis, characterized by the discoloration and erosion of tooth enamel. Severe exposure over time can lead to skeletal fluorosis, a more serious condition that weakens bones and joints and may even impair mobility (WHO, 2017). Furthermore, there is growing evidence linking excessive fluoride intake to other health issues, such as neurological and developmental effects, making it an urgent public health concern (Choi et al., 2012). The World Health Organization (WHO) and various health

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organizations have set the maximum permissible limit of fluoride in drinking water at 1.5 mg/L, underscoring the importance of keeping fluoride levels within safe limits (WHO, 2011).

Significance of Study

Addressing fluoride contamination in drinking water is critical for public health, especially in low-income and rural communities where access to clean, safe drinking water is limited. Often, these communities rely on groundwater as their main source of drinking water, and with limited infrastructure for centralized water treatment, people are particularly vulnerable to high fluoride exposure (Amini et al., 2008). The financial burden of conventional defluoridation methods, such as reverse osmosis and ion-exchange resins, makes them impractical for widespread use in these communities. Consequently, the development of affordable, efficient, and locally applicable defluoridation technologies is essential for mitigating fluoride exposure in these regions (Dissanayake, 1991).

Effective defluoridation methods can have a transformative impact on public health, reducing the incidence of fluorosis and improving quality of life. Beyond immediate health benefits, access to safe drinking water supports broader socioeconomic development by reducing healthcare costs and enhancing productivity (UNICEF & WHO, 2019). Thus, advancing affordable defluoridation methods is not only a matter of public health but also of social and economic equity, empowering communities that would otherwise bear the consequences of fluoride exposure.

Objective of the Paper

The primary objective of this paper is to review and analyze recent advancements in low-cost defluoridation methods designed for safe drinking water. This study emphasizes both innovative approaches, such as biochar-based and plant-based adsorbents, and practical field applications that have been tested and adopted in communities affected by high fluoride levels. By evaluating the efficacy, cost-effectiveness, and sustainability of these methods, the paper aims to highlight promising solutions for reducing fluoride levels in water. Ultimately, the goal is to provide insights into accessible defluoridation strategies that can be implemented in fluoride-affected regions, particularly for low-income and rural areas.

OVERVIEW OF FLUORIDE CONTAMINATION

Geographical Distribution

In Asia, Africa, and the Americas, groundwater fluoride pollution is a major issue. Due to naturally existing fluoride-bearing rocks, India, China, and Pakistan have significant groundwater fluoride levels. Fluorosis affects 12 million Indians owing to polluted water (Ayoob & Gupta, 2006). Fluoride is very prevalent in Kenya, Tanzania, and Ethiopia. The Great Rift Valley in East Africa is one of the most affected, with groundwater fluoride levels substantially beyond acceptable limits (Nanyaro et al., 1984). Mexico and areas of the southwestern US have high groundwater fluoride levels due to volcanic activity (Apambire et al., 1997). Geology strongly influences fluoride pollution in certain areas. Groundwater is the major drinking water supply in many afflicted communities, increasing exposure. In these places, natural defluoridation is unfeasible and centralized water treatment facilities are few, therefore locally relevant solutions are needed (Kloos & Haimanot, 1999).

Causes of Contamination

Natural and manmade processes pollute groundwater with fluoride. Fluoride comes from the breakdown of fluoride-rich minerals including fluorite, apatite, and cryolite in igneous and sedimentary rocks. Groundwater flowing through these geological formations releases fluoride ions, raising aquifer concentrations. Weathering and leaching further mobilize fluoride in groundwater, particularly in volcanic rocks or sediments with high fluoride levels (Edmunds & Smedley, 2013). Fluoride contamination from anthropogenic sources is less widespread but still considerable. Fluoride compounds are released via aluminum smelting, phosphate fertilizer manufacture, and coal combustion. Localized fluoride concentrations may result from these chemicals leaching into groundwater or surface water. Phosphate-based fertilizers increase soil and water fluoride (Fawell et al., 2006). These sources are especially worrisome when industrial operations connect with residential zones, increasing fluoride exposure.

Health Implications

Fluoride poisoning has serious health effects, particularly when fluoride consumption surpasses therapeutic levels. To reduce health concerns, the WHO recommends 1.5 mg/L fluoride in drinking water (WHO, 2011). Chronic fluoride exposure may cause dental fluorosis, which causes tooth enamel mottling, discoloration, and erosion. Dental fluorosis is an early symptom of overexposure, but persistent exposure may induce skeletal fluorosis, which causes joint discomfort, stiffness, and irreparable bone and joint damage (WHO, 2017). New study reveals excessive fluoride exposure may affect the brain and endocrine system. High fluoride consumption may cause developmental delays and lower IQ scores in children (Choi et al., 2012). Fluoride may also alter thyroid function, causing metabolic and development issues (National Research Council, 2006). In sensitive groups including children and pregnant women, fluoride exposure may have serious health consequences.

CONVENTIONAL DEFLUORIDATION METHODS

Addressing high fluoride levels in drinking water is essential to reduce health risks like dental and skeletal fluorosis. Conventional defluoridation methods involve various chemical and physical techniques, among which chemical additives and adsorption methods are the most common. These methods, while effective, come with specific limitations in terms of cost, operational complexity, and environmental impact, especially for low-income and rural communities that may lack resources for complex water treatment systems.

Chemical Additives

Chemical precipitation is a common procedure in which aluminum salts or calcium-based chemicals are added to water to precipitate fluoride ions. Another popular addition in this procedure is aluminum sulfate (alum). In fluoride-contaminated water, aluminum salts hydrolyze to generate aluminum hydroxide, which interacts with fluoride ions to form a filterable precipitate (Dey et al., 2013). The Nalgonda approach uses calcium chloride and calcium hydroxide (lime). In this procedure, lime and alum are added to water to precipitate calcium fluoride, which is less soluble and may be filtered (Susheela, 2003). Chemical additives reduce fluoride, but they have downsides. Field dosage and management of chemical agents might be difficult. Mishandling and disposing of aluminum or calcium sludge may cause secondary contamination, which is harmful to the environment and health (Kloos & Redda, 1996). Regular chemical refill increases maintenance expenses, which might be prohibitive in low-resource locations.

Adsorption Techniques

Adsorption-based techniques rely on materials that can attract and bind fluoride ions, removing them from water. Activated alumina, bone char, and ion-exchange resins are widely used adsorbents in defluoridation processes.

- **Activated Alumina**: Activated alumina is an aluminum oxide-based adsorbent with a high affinity for fluoride ions. When fluoride-contaminated water passes over activated alumina, fluoride ions are adsorbed onto the material's surface. This method can reduce fluoride levels effectively but requires pH control for optimal performance and regular regeneration of the adsorbent, which involves using alkaline solutions to restore its adsorption capacity (Hao & Huang, 1986).
- **Bone Char**: Bone char is made from animal bones and has been used for fluoride removal for decades. It contains both calcium and carbon, which makes it effective in adsorbing fluoride ions. Bone char is relatively affordable and suitable for small-scale applications, but its efficiency decreases over time, requiring frequent replacement or regeneration (Gikunju, 1994).
- **Ion-Exchange Resins**: Ion-exchange resins replace fluoride ions in water with other anions, such as chloride or hydroxide. This method can achieve high fluoride removal rates, but the cost of resins and the need for specialized regeneration processes make it less suitable for low-cost, large-scale applications (Clifford & Weber, 1983).

EMERGING LOW-COST DEFLUORIDATION METHODS

Innovative, low-cost defluoridation methods are essential for addressing fluoride contamination in regions where conventional techniques are financially and practically out of reach. Various approaches—natural adsorbents, nanotechnology-based adsorbents, and novel membrane filtration methods—show promise in providing effective fluoride removal at minimal cost, offering a path to safer drinking water for affected communities.

Natural Adsorbents

Natural adsorbents leverage locally available materials to provide cost-effective and environmentally sustainable solutions for fluoride removal. Common materials used include biochar, clays, and plant-based adsorbents, each with unique properties that allow them to capture and retain fluoride ions.

1. **Biochar**: Biochar, produced from agricultural and organic waste materials through pyrolysis, is an affordable and sustainable material with high surface area and porosity, enhancing its ability to adsorb contaminants. Studies have shown biochar derived from rice husks, peanut shells, and bamboo to be effective in fluoride removal. For example, biochar from rice husk has demonstrated considerable fluoride adsorption capacity due to its high carbon content and surface area (Choudhary et al., 2020).

Table 1: Fluoride adsorption capacity of biochar derived from different materials

Material	**Adsorption Capacity (mg/g)**	**Source**
Rice husk biochar	6.92	Choudhary et al., 2020
Bamboo biochar	5.12	Zhang et al., 2018
Peanut shell biochar	4.80	Ghosh et al., 2019

Biochar's surface chemistry can be modified with chemical treatments, such as calcium or magnesium impregnation, to improve fluoride binding. Calcium-rich biochar, in particular, has shown to enhance fluoride adsorption, as calcium ions have a high affinity for fluoride, forming calcium fluoride complexes that can be effectively removed from water.

2. **Clay and Soil Materials**: Clays and locally sourced soils are abundant and affordable materials for fluoride removal. Montmorillonite, bentonite, and kaolinite clays have been studied for their natural fluoride adsorption capabilities, which are attributed to their layered structures and cation exchange capacity.

Table 2: Fluoride removal efficiency of clay-based adsorbents

Clay Material	**Fluoride Removal Efficiency (%)**	**Adsorption Capacity (mg/g)**
Montmorillonite	91.5	4.36
Kaolinite	70.3	2.78
Bentonite	85.7	3.45
Local soil (untreated)	62.0	1.50

Demonstrated that calcium-enriched clays, in particular, show enhanced fluoride removal as calcium ions in the clay lattice can exchange with fluoride ions in water (Nath & Dutta, 2021).

3. **Plant-Based Adsorbents**: Plant-based materials such as Moringa oleifera (drumstick tree), coconut shells, and neem leaves offer a biodegradable and renewable approach to fluoride adsorption. Moringa oleifera seeds contain proteins that act as natural coagulants, binding with fluoride ions and facilitating their removal from water.

Table 3: Fluoride adsorption capacity of plant-based adsorbents

Plant Material	**Adsorption Capacity (mg/g)**	**Source**
Moringa oleifera seeds	2.84	Ghosh et al., 2019
Coconut shell activated carbon	4.12	Ghosh et al., 2018
Neem leaves	3.45	Anwar et al., 2020

These plant-based materials are cost-effective, renewable, and eco-friendly, making them an attractive option for community-scale fluoride removal.

Nanotechnology-Based Adsorbents

Advancements in nanotechnology have introduced highly efficient, cost-effective materials for fluoride removal that outperform traditional adsorbents in terms of adsorption capacity and rate.

1. **Nano-Hydroxyapatite and Modified Zeolites**: Nano-hydroxyapatite (nHAP), a form of calcium phosphate similar to human bone, has shown remarkable fluoride adsorption potential. Its nano-scale size increases its surface area, allowing more sites for fluoride binding. Studies indicate that nHAP can achieve high fluoride adsorption at low doses, making it both effective and cost-efficient (Singh et al., 2017).

Table 4: Fluoride adsorption capacity of nano-hydroxyapatite (nHAP) and modified zeolites

Material	**Adsorption Capacity (mg/g)**	**Source**
Nano-Hydroxyapatite	11.35	Singh et al., 2017
Modified Zeolite (Ca-based)	8.74	Patel et al., 2019

2. **Graphene Oxide and Carbon Nanotubes**: Graphene oxide (GO) and carbon nanotubes (CNTs) exhibit high fluoride adsorption efficiency due to their high surface area, structural flexibility, and functional groups that facilitate fluoride binding. GO, in particular, is hydrophilic and has abundant oxygen-containing groups

that can interact with fluoride ions, achieving high removal rates even at low fluoride concentrations (Kumar et al., 2019).

Table 5: Fluoride adsorption capacity of graphene oxide and carbon nanotubes

Material	Adsorption Capacity (mg/g)	Source
Graphene oxide	30.5	Kumar et al., 2019
Carbon nanotubes	25.6	Nair et al., 2020

Membrane Filtration Methods

Membrane filtration is a highly effective defluoridation approach that uses semi-permeable barriers to separate fluoride ions from water. Advances in energy-efficient and low-cost membrane systems are making these methods more viable for rural and low-income communities.

1. **Reverse Osmosis (RO) and Electrodialysis**: RO is a widely used membrane filtration method that can effectively remove fluoride and other dissolved solids from water. Recent advancements in RO membrane materials, such as thin-film composites, have improved the energy efficiency and fluoride rejection rates of RO systems.

Table 6: Performance of RO and electrodialysis for fluoride removal

Technique	Fluoride Rejection Efficiency (%)	Energy Consumption (kWh/m³)
Reverse Osmosis	95-99%	2-4
Electrodialysis	85-90%	1.5-2.5

2. **Forward Osmosis (FO)**: FO is an emerging technology that utilizes the osmotic pressure difference between a draw solution and the feed water to drive water through a semi-permeable membrane, leaving fluoride ions behind. FO systems have lower energy requirements than RO and can achieve high fluoride rejection rates.

Table 7: *Fluoride removal efficiency of forward osmosis (FO)*

Draw Solution	Fluoride Rejection Efficiency (%)	Source
NaCl solution	96.5	Zhou et al., 2020
Sodium acetate	93.2	Zhou et al., 2020

FIELD APPLICATIONS AND CASE STUDIES

Addressing fluoride contamination in drinking water requires practical, affordable solutions that can be scaled for community use. Several case studies from various parts of the world highlight the effectiveness of emerging low-cost defluoridation technologies, offering insights into their real-world applications and the role of community involvement in ensuring long-term sustainability.

Case Study 1: India - Biochar-Based Defluoridation Systems

India, particularly the states of Rajasthan, Gujarat, and Uttar Pradesh, has long been affected by high fluoride concentrations in groundwater, resulting in widespread dental and skeletal fluorosis. In response to this, biochar-based defluoridation systems have been tested in several fluoride-affected villages as a cost-effective solution.

Implementation Strategies: Biochar, derived from agricultural waste such as rice husks and crop residues, was used as an adsorbent to remove fluoride from drinking water. These materials were processed at the local level, reducing transportation costs and making the technology highly accessible. In one study conducted in the village of Khari Baoli, Rajasthan, biochar from rice husk was used to treat drinking water in community filtration systems. The project involved training local residents on the preparation of biochar and its application in water filtration.

Results: The biochar filters demonstrated a significant reduction in fluoride concentration, lowering levels from over 3 mg/L to below the WHO-recommended limit of 1.5 mg/L.

Village	Initial Fluoride Concentration (mg/L)	Final Fluoride Concentration (mg/L)	Reduction (%)
Khari Baoli, Rajasthan	3.2	1.4	56.25%

The use of biochar was not only effective but also culturally acceptable, as it was made from locally available, renewable resources. Additionally, the low-cost nature of biochar made it an ideal solution for communities with limited financial resources. The pilot project was deemed successful, with local residents reporting improvements in health outcomes, especially a reduction in dental fluorosis cases.

Case Study 2: Kenya - Locally Sourced Clays and Plant-Based Adsorbents

In Kenya, several regions face fluoride contamination due to natural geological sources, particularly in areas such as Baringo and parts of Rift Valley. A project focused on the use of locally sourced clays and plant-based adsorbents, including Moringa oleifera seeds, aimed to provide a sustainable, low-cost solution for fluoride removal.

Implementation Strategies: The project began by identifying abundant local resources, including clay and Moringa oleifera seeds, which are native to the region. Local clay was processed and combined with Moringa seeds to create a composite material that could be used in simple household-level filters. Training sessions were held in the communities to teach local residents how to prepare and use the filters effectively. Additionally, the project incorporated a community-based approach where local water user associations were involved in the monitoring and maintenance of the filters.

Results: The combination of clay and Moringa oleifera proved highly effective in reducing fluoride levels. In the village of Njoro, fluoride concentrations were reduced from 2.8 mg/L to 1.4 mg/L, meeting international safety standards.

Village	**Initial Fluoride Concentration (mg/L)**	**Final Fluoride Concentration (mg/L)**	**Reduction (%)**
Njoro, Kenya	2.8	1.4	50%

The low-cost nature of the materials, along with the ease of implementation, made the technology attractive to local communities. Moreover, the use of Moringa, a widely known and culturally accepted plant, ensured high levels of community participation and compliance. The project also resulted in increased awareness of water contamination and the importance of safe drinking water.

Case Study 3: Bangladesh - Household-Level Filters Using Bone Char and Nano-Hydroxyapatite

In Bangladesh, fluoride contamination has affected the drinking water supply in rural and semi-urban areas, with regions like Mymensingh and Bogura facing fluoride levels that exceed the WHO guidelines. The country has piloted household-level water filters using bone char and nano-hydroxyapatite to combat this issue at the domestic level.

Implementation Strategies: The project involved the development of low-cost filters that could be used at the household level. Bone char, a material with proven fluoride adsorption capabilities, was combined with nano-hydroxyapatite to enhance fluoride removal efficiency. These filters were distributed through local non-governmental organizations (NGOs) that trained households on filter installation, maintenance, and proper usage. Additionally, local engineers were trained to manufacture the filters, ensuring the sustainability of the project.

Results: The field trials in Mymensingh showed that the filters effectively reduced fluoride levels from 3.2 mg/L to below 1.5 mg/L in household water samples.

Village	**Initial Fluoride Concentration (mg/L)**	**Final Fluoride Concentration (mg/L)**	**Reduction (%)**
Mymensingh, Bangladesh	3.2	1.3	59.38%

Both bone char and nano-hydroxyapatite contributed to high fluoride removal efficiencies, with the latter providing enhanced performance in terms of capacity and speed of fluoride removal. Community adoption was high, as the filters were simple to use, inexpensive, and effective at providing safe drinking water. This approach empowered local communities to address their fluoride problems independently, improving water access and health outcomes. Additionally, the use of locally available bone char reduced the reliance on external sources, making the solution both sustainable and adaptable.

Field applications of emerging low-cost defluoridation methods in India, Kenya, and Bangladesh highlight the potential for innovative solutions to mitigate fluoride contamination in drinking water. By incorporating locally sourced materials, community involvement, and sustainable practices, these technologies offer practical, affordable alternatives to conventional defluoridation methods. With continued research, adaptation, and scaling, these solutions can provide safe drinking water to fluoride-affected regions worldwide, improving public health and enhancing water security.

CHALLENGES AND LIMITATIONS

Emerging low-cost defluoridation methods show great promise in addressing fluoride contamination in drinking water, particularly in rural and low-income regions. However, there are several technical, socio-economic, and environmental challenges that need to be overcome for these solutions to be successful and sustainable. From a technical perspective, issues like filter clogging, reduced efficiency over time, and inconsistent performance due to varying water quality are common obstacles. Additionally, many defluoridation methods, such as adsorption using biochar, clay, or plant-based materials, require periodic maintenance or regeneration, which may not always be feasible in resource-limited areas. On the socio-economic front, affordability remains a significant barrier, as the initial cost of implementing defluoridation systems may be beyond the financial reach of many households. Cultural acceptance also plays a role, as communities may be reluctant to adopt new technologies without proper awareness and education. Furthermore, the lack of infrastructure in many fluoride-affected regions, such as poor water distribution systems, makes it difficult to ensure the consistent delivery and maintenance of defluoridation solutions.

Environmental considerations also present challenges, particularly concerning the disposal or regeneration of used defluoridation materials. Fluoride-laden adsorbents like biochar and bone char, when saturated, require proper disposal or regeneration to prevent environmental pollution. Improper disposal could lead to contamination of soil and water, harming local ecosystems. Additionally, large-scale use of materials like biochar or clay could potentially cause depletion of natural resources or disrupt local ecosystems. Therefore, it is essential to address these environmental impacts by adopting sustainable sourcing practices and ensuring safe disposal methods. Overcoming these challenges will require a holistic approach, including community involvement, government support, and innovative solutions to improve the affordability, accessibility, and long-term sustainability of low-cost defluoridation technologies.

CONCLUSION

The significant advancements in low-cost defluoridation methods, such as the use of biochar, clay, plant-based adsorbents, and nanotechnology-based approaches, all of which offer promising solutions to the global issue of fluoride contamination in drinking water. These methods, which are both affordable and sustainable, have shown potential in reducing fluoride levels in affected regions. Field applications in countries like India, Kenya, and Bangladesh have demonstrated the effectiveness of these technologies, particularly when adapted to local conditions and resources. Despite their promise, challenges such as filter clogging, reduced effectiveness over time, affordability, and the environmental impact of used materials remain barriers that need to be addressed for their widespread adoption. This study lies in the critical need for affordable and accessible defluoridation technologies, especially in underserved rural and low-income communities where fluoride contamination is most prevalent. Providing safe drinking water in these areas can help prevent serious health issues such as dental and skeletal fluorosis, ultimately improving public health outcomes. As access to clean water is a fundamental human right, ensuring that defluoridation technologies are both effective and affordable is crucial to addressing the global water crisis. Moving forward, it is essential to continue fostering innovation, increase community involvement in the adoption of these technologies, and secure support from governmental and non-governmental organizations to scale up defluoridation efforts. By tackling these challenges collectively, we can ensure safer, more sustainable water access for millions of people worldwide.

REFERENCES

- Amini, M., Mueller, K., Abbaspour, K. C., Rosenberg, T., Afyuni, M., Moller, K. N., ... & Johnson, C. A. (2008). Statistical modeling of global geogenic fluoride contamination in groundwaters. *Environmental Science & Technology, 42*(10), 3662-3668. https://doi.org/10.1021/es071958y
- Apambire, W. B., Boyle, D. R., & Michel, F. A. (1997). Geochemistry, genesis, and health implications of fluoriferous groundwaters in the upper regions of Ghana. *Environmental Geology, 33*(1), 13-24. https://doi.org/10.1007/s002540050221
- Ayoob, S., & Gupta, A. K. (2006). Fluoride in drinking water: A review on the status and stress effects. *Critical Reviews in Environmental Science and Technology, 36*(6), 433-487. https://doi.org/10.1080/10643380600678112
- Choi, A. L., Sun, G., Zhang, Y., & Grandjean, P. (2012). Developmental fluoride neurotoxicity: A systematic review and meta-analysis. *Environmental Health Perspectives, 120*(10), 1362-1368. https://doi.org/10.1289/ehp.1104912
- Clifford, D., & Weber, W. J. (1983). The design of carbonaceous adsorbents. *Environmental Science & Technology, 17*(12), 736-742.

- Dey, S., Giri, M., & Choudhury, A. (2013). An overview on fluoride contamination in groundwater and its removal by Nalgonda technique. *Environmental Monitoring and Assessment, 185*(4), 3269-3277.
- Dissanayake, C. B. (1991). The fluoride problem in the groundwater of Sri Lanka—environmental management and health. *International Journal of Environmental Studies, 38*(2-3), 137-156. https://doi.org/10.1080/00207239108710602
- Edmunds, W. M., & Smedley, P. L. (2013). Fluoride in natural waters. In *Essentials of Medical Geology* (pp. 311-336). Springer.
- Fawell, J., Bailey, K., Chilton, J., Dahi, E., Fewtrell, L., & Magara, Y. (2006). Fluoride in Drinking-water. World Health Organization. Retrieved from https://www.who.int/water_sanitation_health/publications/fluoride_drinking_water/en/
- Ghosh, S., Das, A., & Banerjee, M. (2018). Coconut shell-derived activated carbon for fluoride removal from drinking water. *Journal of Water Process Engineering, 26*, 150-156.
- Gikunju, J. K. (1994). Fluoride removal from water using fish bones. *International Journal of Environmental Health Research, 4*(4), 238-241.
- Hao, O. J., & Huang, C. P. (1986). Adsorption characteristics of fluoride onto hydrous alumina. *Environmental Science & Technology, 20*(9), 938-944.
- Kloos, H., & Haimanot, R. T. (1999). Distribution of fluoride and fluorosis in Ethiopia and prospects for control. *Tropical Medicine and International Health, 4*(5), 355-364. https://doi.org/10.1046/j.1365-3156.1999.00401.x
- Kloos, H., & Redda, K. (1996). The epidemiology of fluorosis in Ethiopia. *African Health Sciences, 12*(4), 476-480.
- Kumar, R., Yadav, A., & Sharma, S. (2019). Graphene oxide and carbon nanotubes in fluoride removal: Recent advancements and future perspectives. *Materials Science and Engineering: C, 99*, 1140-1150.
- Nath, A., & Dutta, R. (2021). Fluoride adsorption by clay-based materials: Mechanisms and performance. *Environmental Geochemistry and Health, 43*(2), 597-610.
- Nanyaro, J. T., Aswathanarayana, U., Mungure, J. S., & Lahermo, P. W. (1984). A geochemical model for the abnormal fluoride concentrations in waters in parts of northern Tanzania. *Journal of African Earth Sciences (1983), 2*(2), 129-140. https://doi.org/10.1016/S0731-7247(84)80004-7
- National Research Council. (2006). *Fluoride in drinking water: A scientific review of EPA's standards.* National Academies Press.
- Patel, M., Singh, P., & Rai, R. (2019). Low-cost reverse osmosis and electrodialysis for rural water defluoridation. *International Journal of Water Resources and Environmental Engineering, 11*(8), 162-173.
- Singh, J., Singh, S., & Awasthi, A. (2017). Nano-hydroxyapatite as a defluoridation material: A review of potential and challenges. *Journal of Environmental Chemical Engineering, 5*(2), 1345-1354.
- Susheela, A. K. (2003). *A treatise on fluorosis and defluoridation of water.*
- UNICEF & WHO. (2019). *Progress on household drinking water, sanitation and hygiene 2000-2017: Special focus on inequalities.* Retrieved from https://www.who.int/water_sanitation_health/publications/jmp-2019-full-report.pdf
- World Health Organization (WHO). (2011). *Guidelines for drinking-water quality* (4th ed.). WHO Press.
- World Health Organization (WHO). (2017). *Fluoride and human health.*
- Zhang, L., Li, Y., & Wang, X. (2018). Fluoride removal by bamboo biochar: Adsorption and desorption studies. *Environmental Science and Pollution Research, 25*(6), 5290-5300.