International Journal of Engineering Research and Advanced Technology (IJERAT)

DOI: 10.31695/IJERAT.2025.7.2

E-ISSN : 2454-6135

Volume. 11, No.7
August – 2025

Hazardous Effects of Fluoride and Its Removal Techniques: A Review

Saiswapna Rautaray[1], **Anup Kumar Swain**[2*], **Nikhil Ranjan Dash**[2], **Hemalata Patra**[3], **Abanti Sahoo**[1]

[1]Chemical Engineering Department, National Institute of Technology, Rourkela, Odisha, India

[2]Chemical Engineering Department, Indira Gandhi Institute of Technology, Sarang, Odisha, India

[3]CIPET: Institute of Petrochemicals Technology, B-25, CNI Complex, Patia, Bhubaneswar, Odisha, India

---

ABSTRACT

Fluorine (F) is highly electronegative in nature and reactive non-metal element. It is rarely found in pure form. It is found in combined form with other elements except oxygen and noble gases. An inorganic monoatomic F anion is called fluoride (F^-). Although F^- is the reason for healthy teeth and bones, excess F^- can be detrimental to human and animal health. The rising prevalence of F^- related problems with human, animal, and plant health is mostly due to natural geological sources and expanding industrialization. The main source of daily F^- consumption in human is potable water. Dental and skeletal fluorosis is caused by F^- concentrations that are above the recommended limits. Some other effects include programmed cell-death, endocytosis, metabolic disorders, osteoporosis, joint pain, weakness of muscles, non-ulcer dyspepsia, polydipsia, anaemia, etc. For human safety and control, removal of F^- is necessary. Therefore, it is important to gather knowledge on the fundamental problems related to F^- contamination, such as origin of F^- disclosure, negative impact on health, along with the viability of F^- removal techniques. This review provides a comprehensive summary of the F^- removal techniques in recent use along with their benefits and drawbacks.

Key Words: Adsorption, De-fluoridation, Fluorosis, Inverse fluidization, Wastewater.

---

1. INTRODUCTION

One of the most basic necessities of human being is water and the access to drinking or potable water is necessary for retaining good health [1]. The rise in water contamination is due to large human population, urbanization, residential complexes, agricultural practices, and due to other environmental modifications [2]. Excess concentrations of nitrate, arsenic, and F^- ions are among the chemical contaminants that have been proven to have negative effects on the health of living beings. The origin of the F^- contamination might be either anthropogenic or geogenic. Anthropogenic F^- contamination is when there is a large increase in F^- contamination as a result of human activity, while geogenic F^- contamination is when there is a major increase in F^- contamination as a result of natural processes [3]. Sedimentary and igneous-type rocks contain minerals such as sellaite (MgF_2), fluorapatite ($Ca_5(PO_4)_3F$), cryolite (Na_2AlF_6), and fluorite (CaF_2) which enter into potable water naturally. F^- in potable water may have positive or negative effects on human being depending on the concentration and length of continuous intake. Due to particular geographical, economical, and financial disadvantages, some places of the World lack access to potable water [1]. Regions with poor water quality often leads to grave social and health problems. Because of this, providing potable water is considered as a prime concern in many countries. Developed and underdeveloped countries are not able to meet the potable water criteria as per the guidelines. The World Health Organization (WHO) reported that, nearly 783 million people are deprived of improved water sources. It is predicted that half of the World population would face a shortage of potable water by 2025 [4]. Above 200 million individuals rely on water of high F^- concentrations which is above 1.5 mg/L. Concentrations above these limits have been associated with dental and skeletal fluorosis. In mild cases tooth mottling occurs, but bone fragility and neurological problem takes place in severe cases.

[2*] Corresponding author: Dr. Anup Kumar Swain,. E-mail: anup_swain@rediffmail.com
ORCID ID: https://orcid.org/0000-0003-3479-6433

Osteoporosis, kidney disease, cancer, brain malfunction, and bladder cancer may happen. Infertility, Alzheimer syndrome, gastro-intestinal irritation, thyroid disorder, etc. can occur due to high F^- intake [5]. As it shows several adverse effects on human

health, there is a need to develop, on urgent basis, a reliable technology that can effectively remove excess F^- from potable water. Defluoridation is the ideal solution to this problem. Different techniques are currently in use for removing F^- from water/wastewater. The aim of this review article is to briefly describe range of concerns associated with F^- contamination such as sources, its harmful effects, and F^- removal techniques with regard to their applicability.

2. SOURCES OF FLUORIDE

F^- is emitted to the atmosphere both in gaseous as well as in particulate forms [6]. Further, exposure of F^- to the environment can be grouped into natural and anthropogenic sources and industrial wastes [7,8].

2.1 Natural Sources

2.1.1 Water

Especially in urban areas, F^- can be found in rainwater, groundwater, freshwater, saltwater, and other sources [9-11]. The average F^- concentration in seawater is 1 mg/L while the value fluctuates for freshwater. Its average concentration in river water and groundwater are 1.5 and 1.0–35.0 mg/L respectively [12]. Almost 75 to 90% of consumed F^- is absorbed and under acidic stomach condition, hydrogen fluoride is formed inside stomach. The existence of nearby F^- containing minerals affects the quality of ground water (well water) to a greater extent. For example, some regions of Canada and China have elevated F^- levels of 4.3 and 13 mg/L respectively [13]. F^- rich minerals are fluorospar, cryolite, topaz, fluorite, phosphorite, theorapatite, and fluorapatite [14,15]. It enters the water through weathering.

2.1.2 Plants

Small amounts of F^- are found in agricultural foods like vegetables and food grains [16]. These foods adsorb F^- rapidly from soil. Use of different type of fertilizers and pesticides influence the quality of foods. Also it depends on the water used for the production of foodstuffs. Soils with high F^- concentration are mostly found in industrial areas. Tea is another major source of F^- [17,18]. The majority cases of fluorosis are found in some places of China because of higher consumption of tea [18]. Matured tea leaves from the same plant can have up to 10 times higher F^- levels than young tea leaves [19]. The concentration of F^- in different foodstuffs is given in Table 1 [20].

2.1.3 Soil

In normal soil, total F^- level varies between 150 to 400 mg/kg while in heavy clay soil, it is above 1000 mg/kg [21-25]. Use of phosphatic fertilizers increases the F^- contamination of the soil with the level of F^- at around 1 to 1.5% [26]. F^- contaminated soil have toxic effects. These are mixed with underground water due to leaching from the soil [1].

2.1.4 Volcanic Activities

The global animal and plant kingdom is impacted by volcanic eruptions. Ashes from volcanic eruptions have high level of F^- which frequently contaminates the geochemical cycle. F^- has been released as hydrogen fluoride from the volcanic outburst. F^- that has erupted may cover a larger land area and may continue to be in land for decades. Many domestic and wild animals are mostly affected by decaying and leaching of volcanos [7,27,28].

2.2 Anthropogenic Sources

Industrialization and motorization are the cause of high F^- exposure to the environment. Many anthropogenic sources are F^- containing pesticides, fluoridated potable water, and dental products. Some food based F^- sources are tea based drinks, processed foods, and beverages [29]. Some other F^- sources are industrial solvents, local anaesthetics, refrigerants, fire extinguishers, and glass chillers [30]. Contamination also occurs due to air sources. In unpolluted areas, the average F^- concentration is lower than 0.1 $\mu g/m^3$. F^- level is around 2 to 3 $\mu g/m^3$ in industrial areas [27].

DOI : 10.31695/IJERAT.2025.7.2

The primary source of F¯ known to cause endemic fluorosis in many countries is coal burning for domestic use [6,31]. Cattle, buffaloes, sheep, goats, camels, and other animals in the livestock industry have died as a result of industrial release of F¯ rich gases and effluents into the environment [32-35].

2.3 Industrial Wastes

In industries, F¯ salts and hydrofluoric acid plays a significant role. In the past it was mined to be used in aluminium smelting. But currently it is derived from hydrogen fluoride. For the separation of slag in steel-making, usually fluorite is utilized on a large scale. Fluorocarbons are produced by the help of hydrofluoric acid and hydrogen fluoride. Hydrofluoric acid is used to dissolve glass [36]. F¯ is also used in casting technologies, abrasive industry, and automotive industry (for braking system). F¯ wastes generated from these industries in gaseous, liquid, and solid forms pollute the environment.

Table 1. Fluoride levels of different food items

Food items	Fluoride concentration (ppm)	Food items	Fluoride concentration (ppm)
Buffalo milk	3.32-6.85	Apple	1.05-2.20
Wheat	0.51-14.03	Red gram	2.34-4.84
Cow milk	1.73-6.87	Cabbage	4.25-11.30
Rice	0.51-5.52	Peas	10.77
Soybean	4.0	Spinach	9.87-29.15
Bajra	2.76-3.84	Fermented milk items	1.76-93.68
Maize	5.6	Green tea leaf	72.62-89.02
Grape	0.84-1.74	Bengal gram	3.84-4.84

3. APPLICATIONS

F¯ is used for dental caries, for water fluoridation, as biological reagents, and also used in many different industries. Some of these are mentioned here.

3.1 Cavity Prevention

F¯ is used to inhibit tooth decay. It is used to fluoridate water and used in a variety of oral hygiene products [37,38]. Several bacteria in the mouth contribute to tooth decay. Carbohydrate and sugars help these bacteria to create acid. Tooth decay process is stopped by F¯ and it strengthens the tooth enamel. F¯ causes the removal of minerals from the surface of the tooth. F¯ assists in remineralizing the surfaces of tooth and reduces cavity formation [38].

3.2 Water Fluoridation

As a dental caries prevention measure, in 1945, several areas of the United States (US) started fluoridating their water supply [39]. Approximately three out of four Americans currently have access to fluoridated potable water. Distinct forms of F¯ such as sodium fluorosilicate, fluorosilicic acid, and sodium fluoride are added to various water systems [40]. In the US, F¯ is present in several sources of natural potable water, though the amounts vary from region to region. The US Public Health Service advisory for supply water is to have 0.7-1.2 mg/L of F¯ for the prevention of tooth decay [40-42]. Permitted value of F¯ depends on the annual average air temperature of the location. 2.4 mg/L is the permissible level for bottled water without additional F¯ at very lower temperatures. The US Food and Drug Administration recommends that manufacturers should keep their F¯ value within 0.7 mg/L [40]. But F¯ value of 1.5 mg/L is decided by the WHO [13].

3.3 Biological Reagent

DOI : 10.31695/IJERAT.2025.7.2

In biological test processing, F^- salts are frequently employed to block the function of protein tyrosine phosphatase [43]. F^- tries to copy the nucleophilic hydroxide ion. These ions are present at active site of enzymes [44]. Aluminum and beryllium fluorides act as phosphatase inhibitors. These two compounds have similar structure to phosphate group. Also they can function in a manner similar to the transition state of the reaction [45,46].

4. HAZARDOUS EFFECTS OF FLUORIDE

4.1 Health Impact of Fluoride on Humans

Due to higher F^- concentration, different kinds of diseases occur in human body. Different diseases occurring with their F^- concentration is presented in Table 2 [15].

4.1.1 Dental Fluorosis

The main component of tooth enamel is crystalline hydroxyapatite. Under normal conditions, in calciferous tissue enamel, apatite crystal lattices are incorporated with F^- ions during its formation. The ion of hydroxyl group is replaced by F^- because stability of fluorapatite is higher than hydroxyapatite [47]. In dental fluorosis, white spots on the surface of tooth enamel occur in mild cases. In severe cases, yellowish brown to black stains and extensive tooth pitting takes place. At the age of 8 to 10 years, dental fluorosis is highly visible which is based on the quantity of F^- consumption [48]. If the teeth have developed to their fullest extent before the excessive F^- exposure, the effects of dental fluorosis may not be immediately noticeable. So at adult age, if there is no symptom of dental fluorosis that does not confirm that their F^- intake is in safe range [15]. Nearly half of the consumed F^- is eliminated from human body by sweat, urine, and faeces [47].

4.1.2 Skeletal Fluorosis

Children and adults both suffer from skeletal fluorosis which is not easily detected unless an advanced stage is reached. F^- generally gets deposited in the joints resulting into difficulty in walking. At the initial stages limb tingling, muscle weakness, or stiffness in back may be experienced which may lead to osteoporosis at a later stage. Even it may cause rare bone cancer or may damage nervous system [49].

4.1.3 Other Ill-effects

High amount of F^- may also affect muscle fibre; urinary tract; respiratory, excretory, reproductive, gastrointestinal, or nervous systems; immunity; liver; kidney; red blood cells; or haemoglobin levels. It also destroys several enzymes [15]. Thyroid disorder, osteoporosis, brain damage, cancer as well as Alzheimer syndrome are the result of excess F^- intake [50]. Excess F^- levels have the potential to disrupt the synthesis of DNA as well as disrupt the metabolism of vitamins, carbohydrates, lipids, proteins, and minerals. Brain and pineal gland can also be damaged by high F^- consumption [51]. Abnormal behaviour in animals as well as reduction of human IQ are the effects of high F^- intake [52].

Table 2. Diseases occurring with their fluoride concentration

Diseases	Concentration of fluoride (mg/L)
Dental fluorosis	1.0-3.0
Stiffened and brittle bones	3.0-4.0
Crippling fluorosis	4.0-6.0 and above

4.2 Effect of Fluoride Contamination in Animals

High concentration of F^- also affect animals [7,53,54]. Food intake and body weight gain reduces due to F^- poisoning in animals [55,56]. Antioxidant enzymes such as catalase, glutathione peroxidase, and superoxide dismutase lose their activities. Easy penetration of F^- through the blood brain barrier resulted in neurodegeneration due to imbalances between oxidant and antioxidant levels [7]. Insecticide formulations contain F^- which if accidentally taken by animals

DOI : 10.31695/IJERAT.2025.7.2

may cause intoxication [57]. Neurodegeneration is mostly attributed due to oxidative damage caused by excessive formation of reactive free radicals which is F^{-} induced [58].

F^{-} is absorbed directly from the water by aquatic animals like fish and invertebrates [51]. Marine bivalves are affected by F^{-} accumulation on the shell and meats [59]. Water temperature, exposure time, and F^{-} concentration affect the toxicity of F^{-} in fishes [60]. Despite the possibility of removal through excretory systems, it frequently accumulates in the fish bone tissue and in the exoskeleton of invertebrates. F^{-} also affects the enzymatic activities in fish [61].

Cows and other domestic animals show signs of skeletal and dental fluorosis. Some signs of nonskeletal fluorosis in these animals are excessive urine discharge, repeated abortions, intermittent diarrhoea, stillbirths, and colic [62].

4.3 Effect of Fluoride Contamination in Plants

F^{-} reduces quantity as well as quality of grains, fruits, vegetables, protein, fat, sugar, and forage [63]. F^{-} concentration, time of exposure, and types of algal species has great impact on the growth of algae which either accelerate or retard the growth of algae. Some algae can withstand high F^{-} concentration of 200 mg/L. Its ions hamper the cell division process governed by nucleotide and nucleic acid metabolism [64].

Varying levels of F^{-} are found in several foodstuffs such as in vegetables and fruits it is 0.1 to 0.4 mg/kg whereas in barley and rice it is up to 2 mg/kg [65]. Tea leaves has high F^{-} concentration of which 25 to 84% being dissolved in the liquor [66]. For agricultural land, source of F^{-} is phosphatic fertilizers [67]. *Freesia*, *Gladiolus*, and some other plant species show toxic indications at low F^{-} concentrations of 20 µg/g dry weight. Whereas *Camellia* and Elderberry plant species show no toxic symptoms up to 3600 µg/g dry weight of F^{-}. Toxic signs shown in plants are the reduction in chlorophyll production, leaf drop, and leaf necrosis [68]. Also tip burning and finally death of plants occurs in high F^{-} contaminated soil [69].

5. FLUORIDE CONTAMINATION IN INDIAN SCENARIO

Including India, 23 nations of the World is severely affected by F^{-} contaminated water. 177 districts of 20 Indian states face the problem of F^{-} contamination and among these Andhra Pradesh, Haryana, Rajasthan, Punjab, Uttar Pradesh, Tamil Nadu, and Gujarat are the most affected states. F^{-} concentration of half of Indian rivers is between 0.1 to 12 ppm [51]. In Rajasthan, people have no other option than using F^{-} contaminated water of up to 44 mg/L resulting into permanent deformities [70]. Fluorosis is a problem in some areas of the Anantapur district in Andhra Pradesh where the F^{-} concentration is between 0.56 and 5.8 mg/L [71]. A number of defluoridation techniques that have been developed, have higher operational and maintainance costs [72]. Developing countries stay away from adopting the expensive techniques [73]. One of the affordable and well-known defluoridation techniques used extensively in India is the Nalgonda technique. Coagulation and precipitation is the basic principle of Nalgonda technique [51,72]. In India, around 620 lakh people are facing the problem of fluorosis due to high F^{-} content of water [71]. In Odisha state, out of 30 districts, the potable water found in 27 districts is highly contaminated with F^{-} and 18 districts are affected by the problem of fluorosis [74].

6. FLUORIDE REMOVAL TECHNIQUES

Defluoridation refers to the lowering of F^{-} level to a recommended level of potable water and is considered to a reliable approach in the areas affected by fluorosis [75]. For the elimination of excess F^{-} from ground water in practical and affordable way, numerous techniques have been developed such as adsorption, reverse osmosis (RO), nanofiltration (NF), electrodialysis (ED), precipitation, ion-exchange, electrocoagulation (EC), freeze concentration, fluidized bed technology, biological treatment, nanotechnology, and hybrid techniques [76-80]. These techniques have their own strengths and weaknesses which are presented in Table 3.

Table 3. Strengths and weaknesses of different defluoridation techniques

Technique	**Strengths**	**Weaknesses**
Adsorption	• High performance • Cost effective Ease of operation Highly eco-friendly	• Strong *p*H dependence • Influence of other ions • Regeneration requirement
Precipitation	• Low water wastage • Low energy requirement No change in taste and odour	• Heavy sludge formation • Produce high residual aluminium
NF	• Highly efficient F^- removal • Organic debris, bacteria, and suspended particles are all effectively rejected • Apply at wide *p*H range	• Membrane fouling Chemical resistance Shorter membrane lifetime Unsatisfactory elimination of some compounds
RO	• Longer lifetime of membrane • Less operative attention	• Expensive technique • Limited membrane regeneration High generation of acidic water
Dialysis and Electrodialysis	• High amount of water recovery • No membrane fouling • No requirement for specific solution storage	• Unsuitable for rural areas • High voltage dependent • Intensive pre-treatment requirement • Frequent replacement of electrodes
Ion-exchange	• No change in taste and colour • Resins have greater flexibility • Better sorption capacity	• Sludge disposal issues • Costly process • Used for small community systems
NPs	• Effective technique	• Costly process
EC	• Separating organic matter is more efficient and quick • *p*H control is not necessary • Good efficiency	• Inhibited during continuous operation by anode passivation and sludge formation on electrodes • High power consumption • Costly process

6.1 Adsorption

It is the practice of removing an element from one phase (liquid/gas) by depositing it at the interface between the liquid/gas and solid phases. By lowering the surface tension between the liquid phase and solid adsorbent, adsorbate is able to get adsorbed on the surface of solid adsorbent [2]. This method is generally used for the removal of F^- because of its better removal efficiency, selectivity, ease of handling, lower operating cost, ability to produce less sludge, and ability to regenerate used adsorbent [80].

Literatures revealed that some natural and synthetic materials in raw or treated form are used as adsorbents for the removal of F^- from potable water/wastewater. Some of these adsorbents are: neem stem charcoal [81], nanoporous Fe–Ce–Ni [82], tri–metal (Fe–Ca–Ce) oxide [83], hydrous hybrid Fe–Ca–Zr oxide [84], mechanochemically activated kaolinites [85], lanthanum–impregnated silica gel [86], heavily–weathered Tertiary soil (composed of quartz, feldspar, illite, and goethite) [87], thermally treated hydrotalcite [88], meso–structured zirconium phosphate [89], granular ferric hydroxide [90], amorphous alumina supported on carbon nanotubes [91], hydrous bismuth oxides [92], Tunisian clay minerals [93], cement paste [94,95], aluminum impregnated hierarchal web of carbon fiber [96], hydrous aluminum oxide embedded with iron oxide nanoparticle [97], bleaching powder [98], calcined Mg–Al–CO_3 layered double hydroxides [99], nano Fe–Al–Ce [100], lanthanum incorporated chitosan [101,102], granular ceramic [103], montmorillonite [104], calcite [105], *Moringa oleifera* seed [106,107], red mud [8,108], rice straw ($KMnO_4$–modified) [109], modified attapulgite [110], laterite [111], magnesia-amended activated alumina [112], polymer/alumina composite [113], Amberlite resin [114], Fe(III)–Al(III)–Cr(III) mixed oxide [115], activated clay [116], Zn/Al/Cl anionic clay [117], Zn/Al hydrotalcite anionic clay [118], manganese oxide coated alumina [119], schwertmannite [120,121], diatomite [122], marble waste powder [123], tea waste with Al/Fe oxides [124], fly ash [125], pumice [126], modified bentonite clay [127], natural zeolite [128], wastes from alum manufacturing process [129], bauxite [130], grapheme [131], iron ore [132], bone char [133], activated alumina [134], alum-impregnated activated alumina [135], aluminium oxide coated pumice [136], protonated chitosan bead [137], cellulose hydroxyapatite nanocomposite [138], orange juice residue [139], acid-treated bentonite [140], aluminum modified iron oxides [141], laterite [142], charcoal containing aluminum and iron oxides [143], banana peel and coffee husk [144], termite mound [145], bleaching earth [146], titanium rich bauxite [147], palm shell [148], Zr-Mn composite [149], ZrCr layered double hydroxides [150], and CeO_2–ZrO_2 nanocage [151].

Removal of F^- depends on several factors such as initial F^- ion concentration, adsorbent dose, reaction/contact time, *p*H, temperature, method of preparation of adsorbent, shaking speed, and presence of co-existing anions. From Table 4 it can be seen that adsorbents such as Lanthanum–impregnated silica gel, calcite, manganese oxide coated alumina, alum-impregnated activated alumina, termite mound, and rice straw can be used to remove F^- above 99%.

Table 4. Comparison among F^- removal by different adsorbents

Adsorbent	**Reactor**	**Operational conditions**		**Maximum % removal**	**Ref.**
Neem stem charcoal	Mechanical shaker 100 rpm	IFIC AD RT pH T	2 to 10 mg/L 1 to 5 g/L 0.5 to 3 h 2 to 10 25 to 55°C	94%	[81]
Nanoporous Fe–Ce–Ni	Shaker 150 rpm	IFIC AD	5 to 45 mg/L 0.04 to 0.4 g/L 0.033 to 0.75 h	98.7%	[82]

		RT pH T	2 to 12 30 to 50°C		
Tri–metal (Fe–Ca–Ce) oxide	Shaker 150 rpm	IFIC AD RT pH T	5 to 50 mg/L 0.02 to 0.25 g/L 0.083 to 1.33 h 2 to 10 30 to 50°C	≈ 98%	[83]
Hydrous hybrid Fe–Ca–Zr oxide	–	IFIC AD RT pH T	5 to 45 mg/L 0.04 to 0.5 g/L 0.083 to 0.83 h 2 to 12 30 to 50°C	96%	[84]
Mechanochemically activated kaolinites	Shaker 125 rpm	IFIC AD RT pH T	2 to 10 mg/L 10 to 50 g/L 0.167 to 1 h 3 to 11 30 to 50°C	≈ 88%	[85]
Lanthanum–impregnated silica gel	Shaker	IFIC AD RT pH T	10.45 to 104.5 mg/L 4 g/L 24 h 2 to 11 20°C	> 99.9%	[86]
Heavily–weathered Tertiary soil	Shaker	IFIC AD RT pH T	10 mg/L 33.33 g/L 48 h 7 to 7.1 25°C	30%	[87]
Hydrotalcite	Shaker	IFIC AD RT	5 mg/L 10 g/L 0.25 to 24 h 5 to 9	97%	[88]

		pH T	Room temperature		
Meso–structured zirconium phosphate	Shaker 200 rpm	IFIC AD RT pH T	1 to 10 mg/L 0.1 to 1 g/L 0.033 to 1 h 2 to 12 10 to 50°C	96%	[89]
Granular ferric hydroxide	Mixer 300 rpm	IFIC AD RT pH T	3 to 7 mg/L 5 g/L 0.167 to 0.5 h 6 to 8 Room temperature	88%	[90]
Amorphous alumina supported on carbon nanotubes	Shaker	IFIC AD RT pH T	1 to 50 mg/L 2 g/L 12 h 3 to 11 Room temperature	57.4%	[91]
Hydrous bismuth oxides	Shaker	IFIC AD RT pH T	10 to 35 mg/L 10 to 100 g/L 1 to 6 h 4 to 12 20 to 50°C	65%	[92]
Tunisian clay minerals	Shaker	IFIC AD RT pH T	2360 mg/L 33.33 g/L 2 h to 8 d 2 to 3 25°C	98%	[93]
Cement paste	Triangular flask 40 rpm	IFIC AD RT	100 mg/L 0.1 to 1 dry weight % of the liquid 48 h 1.7 to 12.5	92.6%	[94,95]

DOI : 10.31695/IJERAT.2025.7.2

		pH T	22±0.5°C		
Hydrous aluminum oxide embedded with iron oxide nanoparticle	Shaker 280 rpm	IFIC AD RT pH T	20 to 60 mg/L 1 g/L 0.0017 to 4 h 5 to 9 25 to 50°C	90.92%	[97]
Bleaching powder	Rotary shaker 150 rpm	IFIC AD RT pH T	5 to 40 mg/L 10 to 100 g/L 1 h 3 to 12 30°C	90.6%	[98]
Calcined Mg–Al–CO_3 layered double hydroxides	Stirrer	IFIC AD RT pH T	10 to 200 mg/L 1.1 g/L 5 to 6 h 5 to 10 30 to 80°C	98%	[99]
Lanthanum incorporated chitosan	Orbital shaker 150 rpm	IFIC AD RT pH T	5.34 mg/L 0.2 to 2 g/L 24 h 3 to 9 30°C	97%	[101, 102]
Granular ceramic	Mechanical shaker 120 rpm	IFIC AD RT pH T	5 to 50 mg/L 20 g/L 72 h 1 to 12 20 to 50°C	88.6%	[103]
Montmorillonite	Magnetic stirrer 700 rpm	IFIC AD RT pH	4 to 120 mg/L 8 g/L 0.167 to 4 h 2 to 10 25°C	65%	[104]

		T			
Calcite	Constant temperature water bath	IFIC AD RT pH T	2.97 to 2100 mg/L 33.33 g/L 72 h 6.38 to 10 22°C	99%	[105]
Moringa oleifera seed	Jar test apparatus 30 to 120 rpm	IFIC AD RT pH T	2 to 10 mg/L 2.5 g/L 0.017 to 1.25 h – Room temperature	92.5%	[106]
Moringa oleifera seed	Conical flask	IFIC AD RT pH T	0.5 to 2 mg/L 0.1 to 2.5 g/L 0.5 to 2.5 h 1 to 10 Room temperature	98%	[107]
Red mud	Conical flask 700 rpm	IFIC AD RT pH T	100 to 1000 mg/L 1 to 8.4 g/L 0.25 to 4 h 1 to 10 Room temperature	82%	[8]
Red mud	Conical flask 400 rpm	IFIC AD RT pH T	5 to 150 mg/L 5 g/L 0.25 to 9 h 2.5 to 7.3 25°C	92.33%	[108]
Rice straw	Shaker	IFIC AD RT pH T	20 mg/L 0.25 to 5 g/L 1 to 24 h 2 to 11 25 to 55°C	100%	[109]

Modified attapulgite	Thermostatic shaker 100 rpm	IFIC	20 to 200 mg/L	87.5%	[110]
		AD	4 g/L		
		RT	48 h		
		pH	6.57		
		T	20 to 40°C		
Laterite	Orbital shaker 150 rpm	IFIC	3 to 50 mg/L	> 98%	[111]
		AD	0.25 to 2 g/L		
		RT	24 h		
		pH	3 to 11		
		T	15 to 42°C		
Magnesia-amended activated alumina	Orbital shaker 90 rpm	IFIC	5 to 30 mg/L	> 95%	[112]
		AD	4 g/L		
		RT	0 to 6 h		
		pH	2 to 10		
		T	30°C		
Polymer/alumina composite	Shaking thermostat machine 120 spm	IFIC	2 to 10 mg/L	80%	[113]
		AD	0.5 to 4 g/L		
		RT	0.083 to 0.5 h		
		pH	3 to 9		
		T	30 to 50°C		
Amberlite resin	Shaker	IFIC	5 mg/L	92.7%	[114]
		AD	1.25 to 10 g/L		
		RT	0 to 1 h		
		pH	1 to 10		
		T	25°C		
Fe(III)–Al(III)– Cr(III) mixed oxide	Thermostatic shaker 360 rpm	IFIC	10 to 50 mg/L	≈ 90%	[115]
		AD	2 g/L		
		RT	0 to 2 h		
		pH	3 to 10		
		T	10 to 45°C		
Activated clay	Shaker	IFI	13 mg/L	66%	[116]

DOI : 10.31695/IJERAT.2025.7.2

	waterbath	C AD RT pH T	15 g/L 0 to 1 h 4 45°C		
Zn/Al/Cl anionic clay	Thermostatic shaker	IFIC AD RT pH T	4.75 to 57 mg/L 4 g/L 0 to 1 h 2.5 to 10.1 25 to 55°C	93.6%	[117]
Zn/Al hydrotalcite anionic clay	Thermostatic water bath/shaker	IFIC AD RT pH T	2 to 60 mg/L 0.1 to 4 g/L 0.5 to 16 h 4 to 10 30 to 70°C	85.5%	[118]
Manganese oxide coated alumina	Rotary shaker 80 to 90 rpm	IFIC AD RT pH T	5.13 to 32.09 mg/L 5 g/L 0 to 11 h 4 to 12 30°C	> 99%	[119]
Schwertmannite	Shaker waterbath 100 to 300 rpm	IFIC AD RT pH T	5 to 15 mg/L 1 to 4 g/L 0 to 3 h 2.6 to 11.8 25 to 55°C	≈ 83%	[120]
Schwertmannite	Thermostatic shaker 150 spm	IFIC AD RT pH T	10 to 90 mg/L 1 g/L 24 h 3 to 11 22.6 to 40°C	70%	[121]
Diatomite	Orbital shaker 40 to 200 rpm	IFIC	5 to 50 mg/L 10 to 100 g/L	91.3%	[122]

		AD RT pH T	0.083 to 2 h 3 to 11 25°C		
Marble waste powder	Orbital shaker 200 rpm	IFIC AD RT pH T	0 to 45 mg/L 3 to 15 g/L 0.5 to 5 h 3 to 10 30°C	98.66%	[123]
Tea waste with Al/Fe oxides	Vapour-bathing constant temperature vibrator 300 rpm	IFIC AD RT pH T	5 to 200 mg/L 0.4 to 8 g/L 0.017 to 5 h 2 to 11 25°C	87%	[124]
Pumice	Agitator 100 rpm	IFIC AD RT pH T	2 to 7 mg/L 5 to 20 g/L 0.5 to 3 h 4 to 9 25°C	85.75%	[126]
Modified bentonite clay	Rotary shaker 150 rpm	IFIC AD RT pH T	1 to 26 mg/L 1 to 10 g/L 24 h 5 to 9 30°C	≈ 65%	[127]
Wastes from alum manufacturing process	Magnetic stirrer 100 to 1000 rpm	IFIC AD RT pH T	5 to 40 mg/L 4 to 28 g/L 0.083 to 1 h 3 to 10 30°C	85%	[129]
Graphene	Thermostatic water-bath shaker	IFIC AD	5 to 25 mg/L 0.5 g/L 0.033 to 1.83 h	70.6%	[131]

DOI : 10.31695/IJERAT.2025.7.2

		RT pH T	3.6 to 10.2 0 to 50°C		
Iron ore	Orbital shaker 50 to 250 rpm	IFIC AD RT pH T	2 to 29 mg/L 1 to 25 g/L 0.083 to 4 h 3 to 11 22°C	86%	[132]
Bone char	–	IFIC AD RT pH T	10 to 50 mg/L 2 g/L 0.5 to 24 h 6 to 8 20 to 40°C	24.4%	[133]
Activated alumina	Mechanical shaker 80 rpm	IFIC AD RT pH T	2.5 to 14 mg/L 4 to 40 g/L 1 to 10 h 4 to 10 –	69.5%	[134]
Alum-impregnated activated alumina	Horizontal shaker 50 rpm	IFIC AD RT pH T	1 to 35 mg/L 0.5 to 16 g/L 0 to 24 h 4 to 9 Room temperature	99%	[135]
Aluminium oxide coated pumice	Shaker 100 rpm	IFIC AD RT pH T	5 mg/L 1 to 20 g/L 0 to 24 h 3 to 11 20°C	97.8%	[136]
Protonated chitosan bead	Shaker 200 rpm	IFIC AD RT	11 to 19 mg/L 2 to 20 g/L 0.167 to 1 h 3 to 11	≈ 92%	[137]

		pH T	30 to 50°C		
Acid-treated bentonite	Shaker 400 rpm	IFIC AD RT pH T	0 to 20 mg/L 30 g/L 0 to 2 h 2.65 to 11.65 25°C	≈ 61.7%	[140]
Laterite	Incubator shaker 100 to 400 rpm	IFIC AD RT pH T	10 to 50 mg/L 0.2 to 1.2 g 0 to 3.25 h 2 to 11 20 to 40°C	1.95%	[142]
Charcoal containing aluminum and iron oxides	Shaker 300 rpm	IFIC AD RT pH T	2 to 50 mg/L 4 g/L 0 to 24 h 3 to 10 28°C	92%	[143]
Banana peel and coffee husk	Shaker 200 rpm	IFIC AD RT pH T	5 to 20 mg/L 9 to 24 g/L 0.5 to 24 h 2 to 10 Room temperature	≈ 86%	[144]
Termite mound	Horizontal shaker 200 rpm	IFIC AD RT pH T	3 to 155 mg/L 1 to 100 g/L 0 to 1 h 3 to 11 23.5 to 25.5°C	≈ 99%	[145]
Titanium rich bauxite	Shaker	IFIC AD RT pH	2 to 50 mg/L 1 to 4 g/L 0 to 6 h 3 to 9 27°C	≈ 90%	[147]

DOI : 10.31695/IJERAT.2025.7.2

		T			
Palm shell	Incubator shaker 150 rpm	IFIC AD RT pH T	5 to 125 mg/L 0.2 g/L 0.083 to 3 h 3 to 11 25 to 45°C	> 95%	[148]
Zr-Mn composite	Shaker 150 rpm	IFIC AD RT pH T	10 to 45 mg/L 2 to 24 g/L 0.033 to 2.42 h 1 to 10 29°C	90%	[149]
ZrCr layered double hydroxides	Magnetic stirrer 600 rpm	IFIC AD RT pH T	0 to 100 mg/L 0 to 3 g/L 0 to 24 h 2.5 to 11 –	93%	[150]

(IFIC: Initial F^- ion concentration; AD: Adsorbent dose; RT: Reaction time; T: Temperature)

6.2 Precipitation/Coagulation

To facilitate the precipitation of F^- present in contaminated water, salts of Al and Ca are frequently used. The fundamental concept of the process is based on the removal of F^- after it has been adsorbed on the flocs. Although F^- can exist in several soluble forms (F^-, $A1F_4^-$, or AlF^{2+}), it is removed as precipitates of Al like $Al(OH)_{3-x}F_x$ which has to be filtered out [2]. At *p*H values between 5.5 and 7.5, F^- removal is most effective [51].

Many research works suggested that, the Nalgonda technique is a cheap and easy precipitation practice. It is initially tested on a small scale in Senegal, Tanzania, and Kenya. In India, this method was introduced by NEERI, Nagpur [2]. In this method bleaching powder, Al salt such as alum, and lime are added to the contaminated water which causes quick mixing, flocculation, and sedimentation and upon filtration water gets defluorinated [152]. Due to its cost-effectiveness, coagulation technique can be used in developing countries in comparison to the costlier RO system [153]. Also this technique is easy to operate and energy saving in nature [154]. In one study it is reported that for alum dose of 300 mg/L at contact time of 0.75 h and *p*H of 6 the F^- removal was 93.3% [155].

6.3 Nanofiltration

Due to high and specific membrane selectivity, NF technique is considered to be an effective membrane technology as compared to other defluoridation processes like RO and ED [77,156]. It is a low pressure method and is used to eliminate larger dissolved solids in the order of nanometre [2]. This is considered as a bridge between RO and ultrafiltration (UF) [157,158]. Low molecular weight organic compounds as well as monovalent and divalent ions are removed by NF technique [159,160].

Cost factor, fouling, scaling, degradation, and removal of all ions present in water are some of the challenges that this technique needs to overcome [78]. It has less working pressure than RO [161]. NF membranes have a number of benefits over other purification techniques including less energy consumption, high flux, and high retention of organic contaminants and multivalent anion salts [2]. Also it has low operational expenses as compared to RO [162]. It was reported that the F^- removal by polyamide thin film composite NF membrane is more than 80% [157] and composite polyamide NF membrane retained 98% of F^- when used in the cross flow mode [158].

6.4 Reverse Osmosis

By applying hydraulic pressure greater than the osmotic pressure on the side of higher concentration, the solvent molecules are made to pass through the semi-permeable membrane to the side of lower concentration [78,163]. It works under higher pressure and discards more amounts of dissolved solids. Through molecular sieving and ionic exclusion, this technique eliminates both monovalent and divalent by 90–96% and 99% respectively. Properties of raw water, temperature, and pressure are certain factors affecting the efficiency of RO [2]. According to a report, when *p*H was varied between 5.5 and 7 the removal of F^- was between 45 to 90% [164]. Several other researchers reported that the removal of F^- ions using RO membranes was between 94 and 99% [165-168].

6.5 Dialysis & Electrodialysis

In dialysis, membranes are used to retain and segregate the solutes. Ions are electrochemically separated by ED, which uses DC voltage to move the ions through ion-exchange membranes. Water is made to pass through cathode and anode for concentrating the contaminated water to produce diluted or more purified water [2]. It was reported that the removal of F^- from potable water was between 80 to 90% [169] and from tap water was 92% [170].

6.6 Ion-exchange

By allowing the water to pass through ion exchanger (either anion or cation exchangers), unwanted ions can be removed. Greensand and zeolite are frequently used as cation exchangers while inorganic metal oxides are commonly used as anion exchangers [80]. By this method, water is softened and the fluoride ions are removed. The calcium form of strong acid cation exchange resin is used to remove F^- due to its high selectivity towards F^-. These resins are costly. These resins can be regenerated but the regeneration process produces F^- loaded wastes which needs further attention [77]. The efficiency of ion-exchange is low and the presence of anions affects the efficiency. So the use of cation/chelating type resins is recommended [169]. It was reported that the maximum F^- removal was 86% using a strong-base anion resin with polystyrene–divinylbenzene matrix [171].

6.7 Nanoparticles (NPs)

Nanotechnology, using NPs (1 to 100 nm) has become the active research area for the purification of contaminated water in recent years. Some distinct characteristics of NPs include smaller size, higher reactivity, large surface area, easier separation, and a large number of active adsorption sites. These characteristics make the NPs an excellent F^- adsorbent [77]. The CaO NPs have the ability to remove F^- up to 98% within 0.5 h of contact time [172]. With CuO NPs, F^- removal was reported to be more than 89% with removal capacity of 357 mg F^-/g CuO NPs [173]. NPs of gamma alumina prepared by sol–gel method with alcoholic aluminium chloride as precursor showed maximum F^- removal of nearly 23 mg/g [174].

6.8 Bio-nanocomposites and carbon-based adsorbents

Recent studies have established bio-nanocomposites as an effective adsorbent for F^- removal. These include plant biomass, industrial by-products, and agronomical wastes [153]. Carbon has strong attraction towards F^- anions, so carbon-based adsorbents are frequently used for F^- removal [175]. Low cost activated carbon prepared from *Pithecellobium dulce* [153] and *Choerospondias axillaries* [175] are effective in removal of F^-.

6.9 Electrocoagulation

An EC technique emits active coagulant precursors into solution by corroding galvanic anodes, which are typically made of aluminium or iron cations. At the cathode, electrolytic reactions produce hydrogen gas. Its implementation depends on the reactor design as well as on the electrode reliability [176]. Important benefits of EC include less sludge generation, absence of chemical handling, less space requirement, simplicity of operation, and low initial investment [177,178]. Additionally, it eliminates refractory organic contaminants, harmful chemicals, phenolic compounds, naturally occurring organic matter, and other impurities from wastewater [179]. EC technique using aluminum electrodes has become an effective defluoridation method both for potable water and industrial wastewater [180,181]. The number of electrodes and the mode of electrode connection (either monopolar or bipolar) are both crucial factors in this process. For the removal of F^-, bipolar connection was better than monopolar connection [182]. When the initial *p*H was between 6 and 7, over 98% of F^- removal was observed [181]. Over 85% of F^- removal was observed at *p*H of 6 within a short time of 0.5 h [183].

6.10 Freeze Concentration

This technique is useful for treating many organic and inorganic industrial pollutants as well as for removing pollutants from water while ice crystals are formed [77,184]. As it involves low working temperatures, the scaling and corrosion problems are less likely to occur [185]. About 48% of F^- removal from tap water was obtained at −24°C by this technique [185]. Optimal removal of F^- was reported to be around 85% at temperatures between −15 to −20°C for deionized water spiked with fluoride [186].

6.11 Fluidized Bed Technology

Industrial gaseous effluents containing F^- are treated in a fluidized bed reactor containing some metallic bed materials. F^- from effluent react with metals present in the reactor as bed materials and form metallic F^-. Although the fluidized bed technology is not being used widely, but the researchers have observed that the fluidized bed technology is quite effective as the formation of FeF_2, FeF_3, and AlF_3 were confirmed through Inductively Coupled Plasma Mass Spectroscopy (ICP-MS) analysis report [187]. Thus it can be concluded that gaseous F^- gets converted to solid F^- using fluidized bed reactor which is disposed safely for land filling. Recent researches show that a new kind of fluidized bed reactor that is aerobic inverse fluidized bed biofilm reactor (AIFBBR) is being used to treat industrial wastewater containing glucose, $FeSO_4$, aniline, phenol, and 4-chlorophenol as well as wastewater from brewery, refinery, steel, starch, and dairy industries [188]. Industrial liquid effluents containing F^- can also be treated in AIFBBR by suitable microbes.

6.12 Hybrid Techniques

A combination of two or more techniques is termed as hybrid treatment. These include EC and microelectrolysis, RO and NF, precipitation and adsorption, microfiltration (MF) and UF, precipitation and crystallization, EC and floatation, and metal organic frameworks (MOFs) [77]. It was reported that, 93.2% of F^- was removed by a hybrid EC-filtration unit [189]. An EC-MF hybrid technique removed 94.5% of F^- at *p*H of 7.9 [190]. It was reported that by employing MOFs, F^- can be removed from potable water with high efficiency [191]. It was also reported that, MOF based adsorbents have F^- removal capacity of 40 mg/g at 30°C [192] and 42.19 mg/g at 25°C [193]. NF-RO hybrid technique helped Tanzanian waters become free from F^- and natural organic matter [194].

F^- removal efficiencies of some of the methods are presented in Table 5.

Table 5. Comparison among different F^- removal methods

Method	**Equipment**	**Operational conditions**	**Maximum % removal**	**Ref.**
NF (thin film composite polyamide)	Stirred stainless steel feed reactor	35°C, *p*H = 10.01, 14 kg_f/cm^2, 750 L/h	> 98%	[158]
RO (thin film polyamide composite membrane, spiral wound)	RO unit	30°C, *p*H = 7, 2 bar, 15 L/h	95%	[168]

Ion-exchange (monovalent selective ion-exchange membrane)	ED unit	*p*H = 6 to 7, 90 L/h, 24 V, 5 A	82 to 90.3%	[169]
ED (cation & anion exchange membrane)	Two compartment ED unit	25°C, 100 L/h, Cell constant = 0.5 cm^{-1}	92%	[170]
Nanoparticles (CaO)	Shaker	25°C, *p*H = 2 to 10, 400 rpm	98%	[172]
Nanoparticles (CuO)	Shaker	22°C, *p*H = 3 to 13, 0.083 to 2 h	> 89%	[173]
EC	Electrocoagulator	26 to 28°C, *p*H = 5 to 9, 450 rpm, 0.5 to 2 A, 3 h	98%	[181]
EC	Electrochemical cell	25°C, *p*H = 6.4 to 8.1, 250 to 625 A/m^2, 0 to 0.75 h	78 to 83%	[182]
EC	Electocogulation cell	*p*H = 4 to 10, 0 to 1 h, 0 to 600 rpm, 0.13 to 1.38 mA/cm^2	> 85%	[183]
Freeze desalination	Freezer	−5 to −30°C, 2 to 10 h	75 to 85%	[186]
Hybrid technique	EC bath (three chamber)	*p*H = 7.8, 625 A/m^2, 0.75 h	93.2%	[189]
MOF	Shaker	25 to 35°C, *p*H = 3 to 11, 150 rpm, 2.5 h	> 99%	[193]

7. CONCLUSIONS & FUTURE PERSPECTIVES

F^- is abundantly found in the environment. Excess F^- is hazardous to human, animal, and plant health. Adsorption, RO, NF, ED, precipitation, ion-exchange, EC, freeze concentration, fluidized bed technology, biological treatment, nanotechnology, and hybrid techniques are some of the techniques used for defluoridation of water. Among these, the most widely used F^- removal technique is adsorption since it is inexpensive, simple to use, and has an expandable physical mechanism. The effectiveness of F^- removal depends on geographical, chemical, and fiscal conditions of a particular region. Given that each technology has its own benefits and drawbacks, it is suggested to select a method that should take into account the particular requirements and circumstances of the region and type of wastes generated.

Future research requirements include new low-cost materials, highly developed systems with minimal wastes, maximum utilization of generated wastes, and complete removal of F^-. There is a good scope for research to develop AIFBBR which has the potential to degrade F^- from liquid wastewater as there is no side product or hazardous waste generation. Microbes will consume F^- as their survival and growth.

REFERENCES

[1] S. J. Kashyap, R. Sankannavar, and G. M. Madhu, “Fluoride sources, toxicity and fluorosis management techniques – A brief review”, *J. Hazard. Mater. Lett.*, vol. 2, pp. 100033, November 2021, https://doi.org/10.1016/j.hazl.2021.100033.

[2] A. Dhillon, S. Prasad, and D. Kumar, “Recent advances and spectroscopic perspectives in fluoride removal”, *Appl. Spectrosc. Rev.*, vol. 52, no. 3, pp. 175-230, August 2016, http://dx.doi.org/10.1080/05704928.2016.1213737.

[3] L. Panda and B. B. Kar, “High fluoride in the ground water in parts of Khurda and Nayagarh district of Odisha”, *Int. J. Innov. Res. Sci. Eng.*, vol. 2, no. 12, pp. 794-799, 2014.

[4] C. F. Z. Lacson, M. C. Lu, and Y. H. Huang, “Fluoride-containing water: A global perspective and a pursuit to sustainable water defluoridation management – An overview”, *J. Clean. Prod.*, vol. 280, pp. 124236, January 2021, https://doi.org/10.1016/j.jclepro.2020.124236.

[5] A. Bhatnagar, E. Kumar, and M. Sillanpää, “Fluoride removal from water by adsorption – A review”, *Chem. Eng. J.*, vol. 171, no. 3, pp. 811-840, July 2011, https://doi:10.1016/j.cej.2011.05.028.

[6] M. A. Danzon, *Air quality guidelines for Europe*, 2nd ed., no. 91, World Health Organization Regional Publications, European Series, Copenhagen, Denmark, 2000.

[7] V. K. Bharti, A. Giri, and K. Kumar, “Fluoride sources, toxicity and its amelioration: A review”, *Ann. Environ. Sci. Toxicol.*, vol. 2, no. 1, pp. 21-32, January 2017, https://dx.doi.org/10.17352/aest.000009.

[8] Y. Çengeloğlu, E. Kır, and M. Ersöz, “Removal of fluoride from aqueous solution by using red mud”, *Sep. Purif. Technol.*, vol. 28, no. 1, pp. 81-86, July 2002, https://doi.org/10.1016/S1383-5866(02)00016-3.

[9] A. Chowdhury, M. K. Adak, A. Mukherjee, P. Dhak, J. Khatun, and D. Dhak, “A critical review on geochemical and geological aspects of fluoride belts, fluorosis and natural materials and other sources for alternatives to fluoride exposure”, *J. Hydrol.*, vol. 574, pp. 333-359, July 2019, https://doi.org/10.1016/j.jhydrol.2019.04.033.

[10] M. Kumar, R. Goswami, A. K. Patel, M. Srivastava, and N. Das, “Scenario, perspectives and mechanism of arsenic and fluoride co-occurrence in the groundwater: A review”, *Chemosphere*, vol. 249, pp. 126126, June 2020, https://doi.org/10.1016/j.chemosphere.2020.126126.

[11] J. P. Maity, M. Vithanage, M. Kumar, A. Ghosh, D. Mohan, A. Ahmad, and P. Bhattacharya, “Seven 21st century challenges of arsenic-fluoride contamination and remediation”, *Groundw. Sustain. Dev.*, vol. 12, pp. 100538, February 2021, https://doi.org/10.1016/j.gsd.2020.100538.

[12] M. Mousazadeh, S. M. Alizadeh, Z. Frontistis, I. Kabdaşli, E. K. Niaragh, Z. A. Qodah, Z. Naghdali, A. E. D. Mahmoud, M. A. Sandoval, E. Butler, and M. M. Emamjomeh, “Electrocoagulation as a promising defluoridation technology from water: A review of state of the art of removal mechanisms and performance trends”, *Water*, vol. 13, no. 5, pp. 656, February 2021, https://doi.org/10.3390/w13050656.

[13] J. Fawell, K. Bailey, J. Cilton, E. Dahi, L. Fewtrell, and Y. Magara, *Fluoride in drinking-water*, vol. 12, World Health Organization, IWA Publishing, London, UK, September 2013, https://doi.org/10.2166/9781780405803.

[14] S. Jagpat, M. K. Yenkie, N. Labhsetwar, and S. Rayalu, “Fluoride in drinking water and defluoridation of water”, *Chem. Rev.*, vol. 112, no. 4, pp. 2454-2466, February 2012, https://doi.org/10.1021/cr2002855.

[15] Meenakshi and R. C. Maheshwari, “Fluoride in drinking water and its removal”, *J. Hazard. Mater.*, vol. 137, no. 1 pp. 456-463, September 2006, https://doi.org/101016/j.jhazmat.2006.02.024.

[16] H. Kabir, A. K. Gupta, and S. Tripathy, “Fluoride and human health: Systematic appraisal of sources, exposures, metabolism, and toxicity”, *Crit. Rev. Environ. Sci. Technol.*, vol. 50, no. 11, pp. 1116-1193, August 2019, https://doi.org/10.1080/10643389.2019.1647028.

[17] X. C. Zhang, H. J. Gao, T. Y. Yang, H. H. Wu, Y. M. Wang, and X. C. Wan, "Al^{3+}-promoted fluoride accumulation in tea plants (*Camellia sinensis*) was inhibited by an anion channel inhibitor DIDS", *J. Sci. Food Agric.*, vol. 96, no. 12, pp. 4224-4230, March 2016, https://doi.org/10.1002/jsfa.7626.

[18] C. Y. Peng, X. F. Xu, Y. F. Ren, H. L. Niu, Y. Q. Yang, R. Y. Hou, X. C. Wan, and H. M. Cai, "Fluoride absorption, transportation and tolerance mechanism in Camellia sinensis, and its bioavailability and health risk assessment: A systematic review", *J. Sci. Food Agric.*, vol. 101, no. 2, pp. 379-387, August 2020, https://doi.org/10.1002/jsfa.10640.

[19] M. H. Wong, K. F. Fung, and H. P. Carr, "Aluminium and fluoride contents of tea, with emphasis on brick tea and their health implications", *Toxicol. Lett.*, vol. 137, no. 1-2, pp. 111-120, January 2003. https://doi.org/10.1016/s0378-4274(02)00385-5.

[20] K. K. Yadav, S. Kumar, Q. B. Pham, N. Gupta, S. Rezania, H. Kamyab, S. Yadav, J. Vymazal, V. Kumar, D. Q. Tri, A. Talaiekhozani, S. Prasad, L. M. Reece, N. Singh, P. K. Maurya, and J. Cho, "Fluoride contamination, health problems and remediation methods in Asian groundwater: A comprehensive review", *Ecotoxicol. Environ. Saf.*, vol. 182, pp. 109362, October 2019, https://doi.org.//10.1016/j.ecoenv.2019.06.045.

[21] N. Bhat, S. Jain, K. Asawa, M. Tak, K. Shinde, A. Singh, N. Gandhi, and V. V. Gupta, "Assessment of fluoride concentration of soil and vegetables in vicinity of Zinc Smelter, Debari, Udaipur, Rajasthan", *J. Clin. Diagn. Res.*, vol. 9, no. 10, pp. ZC63-ZC66, October 2015, https://doi.org/10.7860/jcdr/2015/13902.6667.

[22] A. Begum, "Soil profiles and fluoride adsorption in intensely cultivated areas of Mysore district, Karnataka, India", *Chem. Sci. Trans.*, vol. 1, no. 2, pp. 410-414, July 2012, https://doi.org/10.7598/cst2012.179.

[23] S. Blagojević, M. Jakovljević, and M. Radulović, "Content of fluorine in soils in the vicinity of aluminium plant in Podgorica", *J. Agric. Sci.*, vol. 47, no. 1, pp. 1-8, 2002, https://doi.org/10.2298/jas0201001b.

[24] M. Hossein, M. J. Rwiza, E. C. Nyanza, R. Bakari, A. Ripanda, S. Nkrumah, J. R. Selemani, and R. L. Machunda, "Fluoride contamination a silent global water crisis: A case of Africa", *Sci. Afr.*, vol. 26, pp. e02485, December 2024, https://doi.org/10.1016/j.sciaf.2024.e02485.

[25] S. Roy and G. Dass, "Fluoride contamination in drinking water – A review", *Resour. Environ.*, vol. 3, no. 3, pp. 53-58, 2013, https://doi.org/10.5923/j.re.20130303.02.

[26] E. Bombik, A. Bombik, K. Górski, L. Saba, T. Bombik, and K. Rymuza, "The effect of environmental contamination by fluorine compounds on selected horse tissues", *Pol. J. of Environ. Stud.*, vol. 20, no. 1, pp. 37-43, January 2011.

[27] L. H. Weinstein and A. Davison, *Fluorides in the environment: Effects on plants and animals*, Cabi Publishing, UK, 2004.

[28] S. Bellomo, A. Aiuppa, W. D'Alessandro, and F. Parello, "Environmental impact of magmatic fluorine emission in the Mt. Etna area", *J. Volcanol. Geotherm. Res.*, vol. 165, no. 1-2, pp. 87-101, August 2007, https://doi.org/10.1016/j.jvolgeores.2007.04.013.

[29] R. Liteplo, R. Gomes, P. Howe, and H. Malcolm, *Environmental health criteria 227: Fluorides*, World Health Organization, Geneva, 2002.

[30] D. Miguez and J. V. Tarazona, "Alkyl hallides", in *Encyclopedia of Toxicology*, 4th ed., vol. 1, P. Wexler, Ed., Academic Press, Elsevier Inc., 2024, pp. 297-300, https://doi.org/10.1016/B978-0-12-824315-2.01166-0.

[31] L. Guijian, Z. Liugen, N. S. Duzgoren-Aydin, G. Lianfen, L. Junhua, and P, Zicheng, "Health effects of arsenic, fluorine, and selenium from indoor burning of Chinese coal" in *Reviews of Environmental Contamination and Toxicology: Continuation of Residue Reviews*, G. G. Ware, Ed., Springer, New York, 2007, pp. 89-106, https://doi.org/10.1007/978-0-387-35368-5_4.

[32] D. Swarup and S. K. Dwivedi, *Environmental pollution and effects of lead and fluoride on animal health*, Indian Council of Agricultural Research, New Delhi, 2002.

[33] D. Swarup, S. Dey, R. C. Patra, S. K. Dwivedi, and S. L. Ali, “Clinico-epidemiological observations of industrial bovine fluorosis in India”, *Indian J. Anim. Sci.*, vol. 71, no. 12, pp. 1111-1115, December 2001.

[34] R. C. Patra, S. K. Dwivedi, B. Bhardwaj, and D. Swarup, “Industrial fluorosis in cattle and buffalo around Udaipur, India”, *Sci. Total Environ.*, vol. 253, no. 1-3, pp. 145-150, May 2000, https://doi.org/10.1016/s0048-9697(00)00426-5.

[35] N. Sahoo and S. K. Ray, “Fluorosis in goats near an aluminium smelter plant in Orissa”, *Indian J. Anim. Sci.*, vol. 74, no. 1, pp. 48-50, January 2004.

[36] J. Aigueperse, P. Mollard, D. Devilliers, M. Chemla, R. Faron, R. Romano, and J. P. Cuer, “Fluorine compounds, Inorganic”, In *Ullmann’s Encyclopedia of Industrial Chemistry*, 6th ed., vol. 15, F. Ullmann, Ed., Wiley-VCH, Weinheim, 2005, https://doi.org/10.1002/14356007.a11_307.

[37] M. S. McDonagh, P. F. Whiting, P. M. Wilson, A. J. Sutton, I. Chestnutt, J. Cooper, K. Misso, M. Bradley, E. Treasure, and J. Kleijnen, “Systematic review of water fluoridation”, *Br. Med. J.*, vol. 321, no. 7265, pp. 855-859, October 2000, https://doi.org/10.1136/bmj.321.7265.855.

[38] US Centers for Disease Control and Prevention, “Community water fluoridation”, https://www.cdc.gov/fluoridation/about/index.html, (accessed on 09 March 2025).

[39] S. Peckham, and N. Awofeso, “Water fluoridation: A critical review of the physiological effects of ingested fluoride as a public health intervention”, *Sci. World J.*, vol. 2014, pp. 293019, February 2014, https://doi.org/10.1155/2014/293019.

[40] American Cancer Society, “Water fluoridation and cancer risk”, www.cancer.org/healthy/cancer-causes/chemicals/water-fluoridation-and-cancer-risk.html, (accessed on 09 March 2025).

[41] National Research Council, *Fluoride in drinking water: A scientific review of EPA's standards (2006)*, The National Academies Press, Washington DC, 2006, https://doi.org/10.17226/11571.

[42] U.S. Department of Health and Human Services Federal Panel on Community Water Fluoridation, “U.S. public health service recommendation for fluoride concentration in drinking water for the prevention of dental caries”, *Public Health Rep.*, vol. 130, no. 4, pp. 318-331, July-August 2015, http://doi.org/10.1177/003335491513000408.

[43] I. Gleiser, P. Yaish, E. Barnea-Gedalyahu, and D. Zharhary, “Phosphatase inhibitor cocktail”, www.sigmaaldrich.com/IN/en/technical-documents/technical-article/protein-biology/protein-lysis-and-xtraction/phosphatase-inhibitor?srsltid=AfmBOopZJjEzt-Mck7V_O1_qlmNOxwPN--9b3qItR4JI9H2jqG3pTpE_ (accessed on 09 March 2025).

[44] G. Schenk, T. W. Elliott, E. Leung, L. E. Carrington, N. Mitić, L. R. Gahan, and L. W. Guddat, “Crystal structures of a purple acid phosphatase, representing different steps of this enzyme's catalytic cycle”, *BMC Str. Bio.*, vol. 8, no. 1, pp. 6, January 2008, https://doi.org/10.1186/1472-6807-8-6.

[45] W. Wang, H. S. Cho, R. Kim, J. Jancarik, H. Yokota, H. H. Nguyen, I. V. Grigoriev, D. E. Wemmer, and S. H. Kim, “Structural characterization of the reaction pathway in phosphoserine phosphatase: Crystallographic “snapshots” of intermediate states”, *J. Mol. Bio.*, vol. 319, no. 2, pp. 421-431, May 2002, https://doi.org/10.1016/s0022-2836(02)00324-8.

[46] H. Cho, W. Wang, R. Kim, H. Yokota, S. Damo, S. H. Kim, D. Wemmer, S. Kustu, and D. Yan, “BeF_3^- acts as a phosphate analog in proteins phosphorylated on aspartate: Structure of a BeF_3^- complex with phosphoserine phosphatase”, *Proc. Natl. Acad. Sci.*, vol. 98, no. 15, pp. 8525-8530, July 2001, https://doi.org/10.1073/pnas.131213698.

[47] A. Lubojanski, D. Piesiak-Panczyszyn, W. Zakrzewski, W. Dobrzynski, M. Szymonowicz, Z. Rybak, B. Mielan, R. J. Wiglusz, A. Watras, and M. Dobrzynski, “The safety of fluoride compounds and their effect on the human body—A narrative review”, *Mater.*, vol. 16, no. 3, pp. 1242, January 2023, https://doi.org/10.3390/ma16031242.

[48] A. Saldarriaga, D. Rojas-Gualdron, M. Restrepo, L. Santos-Pinto, and F. Jeremias, "Dental fluorosis severity in children 8-12 years old and associated factors", *Acta. Odontol. Latinoam.*, vol. 34, no. 2, pp. 156-165, September 2021, https://doi.org/10.54589/aol.34/2/156.

[49] M. S. Sankhla and R. Kumar, "Fluoride contamination of water in India and its impact on public health", *ARC J. Forensic Sci.*, vol. 3, no. 2, pp. 10-15, August 2018, http://doi.org/10.20431/2456-0049.0302002.

[50] A. Ghosh, K. Mukherjee, S. K. Ghosh, and B. Saha, "Sources and toxicity of fluoride in the environment", *Res. Chem. Intermed.*, vol. 39, no. 7, pp. 2881-2915, September 2013, https://doi.org/10.1007/s11164-012-0841-1.

[51] L. P. Praveen, R. Chinthayyanaidu, and P. D. S. Reddy, "Review on the effect of fluoride contamination and methods for fluoride removal with an emphasis on adsorption using low cost adsorbents", *J. Emerg. Technol. Innov. Res.*, vol. 5, no. 6, pp. 470-483, June 2018.

[52] A. S. Palikir and S. S. Mokashi, "Defluoridation of water by Moringa Oleifera - A natural adsorbent", *Int. J. Eng. Sci. Innov. Technol.*, vol. 2, no. 5, pp. 245-252, September 2013.

[53] S. L. Choubisa, "Fluoride in drinking water and its toxicosis in tribals of Rajasthan, India", *Proc. Natl. Acad. Sci., India, Sect. B Biol. Sci.*, vol. 82, no. 2, pp. 325-330, April-June 2012, https://doi.org/10.1007/s40011-012-0047-8.

[54] S. L. Choubisa, "Industrial fluorosis in domestic goats (*Capra hircus*), Rajasthan, India", *Fluor.*, vol. 48, no. 2, pp. 105-112. April-June 2015.

[55] A. L. Khandare, P. U. Kumar, N. H. Shankar, S. Kalyanasundaram, and G. S. Rao, "Effect of calcium deficiency induced by fluoride intoxication on lipid metabolism in rabbits", *Fluor.*, vol. 40, no. 3, pp. 184-189, July-September 2007.

[56] J. Lohakare, A. Pattanaik, and S. A. Khan, "Effect of long-term fluoride exposure on growth, nutrient utilization and fluoride kinetics of calves fed graded levels of dietary protein", *Biol. Trace Elem. Res.*, vol. 138, pp. 148-162, January 2010, https://doi.org/10.1007/s12011-009-8594-4.

[57] G. Eraslan, M. Kanbur, and S. Silici, "Evaluation of propolis effects on some biochemical parameters in rats treated with sodium fluoride", *Pestic. Biochem. Phys.*, vol. 88, no. 3, pp. 273-283, July 2007, https://doi.org/10.1016/j.pestbp.2007.01.002.

[58] V. K. Bharti and R. S. Srivastava, "Fluoride-induced oxidative stress in rat's brain and its amelioration by buffalo (*Bubalus bubalis*) pineal proteins and melatonin", *Biol. Trace Elem. Res.*, vol. 130, pp. 131-140, August 2009, https://doi.org/10.1007/s12011-009-8320-2.

[59] J. A. Nell and G. Livanos, "Effects of fluoride concentration in seawater on growth and fluoride accumulation by Sydney rock oyster (*Saccostrea commercialis*) and flat oyster (*Ostrea angasi*) spat", *Water Res.*, vol. 22, no. 6, pp. 749-753, June 1988, https://doi.org/10.1016/0043-1354(88)90185-6.

[60] J. A. Camargo, "Fluoride toxicity to aquatic organisms: A review", *Chemosphere*, vol. 50, no. 3, pp. 251-264, January 2003, https://doi.org/10.1016/s0045-6535(02)00498-8.

[61] J. A. Camargo and J. V. Tarazona, "Short-term toxicity of fluoride ion (F^-) in soft water to rainbow trout and brown trout", *Chemosphere*, vol. 22, no. 5-6, pp. 605-611, January 1991, https://doi.org/10.1016/0045-6535(91)90071-k.

[62] S. L. Choubisa, V. Modasiya, C. K. Bahura, and Z. Sheikh, "Toxicity of fluoride in cattle of the Indian Thar desert, Rajasthan, India", *Fluor.*, vol. 45, no. 4, pp. 371-376, October-December 2012.

[63] L. H. Weinstein and D. C. McCune, "Effects of fluoride on agriculture", *J. Air Pollut. Control Assoc.*, vol. 21, no. 7, pp. 410-413, July 1971, https://doi.org/10.1080/00022470.1971.10469550.

[64] N. J. Antia and M. E. Klut, “Fluoride addition effects on euryhaline phytoplankter growth in nutrient-enriched seawater at an estuarine level of salinity”, *Bot. Mar.*, vol. 24, pp. 147-152, 1981, https://doi.org/10.1515/botm.1981.24.3.147.

[65] R. Gautam, N. Bhardwaj, and Y. Saini, “Fluoride accumulation by vegetables and crops grown in Nawa Tehsil of Nagaur district (Rajasthan, India)”, *J. Phytol.*, vol. 2, no. 2, pp. 80-85, October 2010.

[66] K. F. Fung, Z. Q. Zhang, J. W. C. Wong, M. H. Wong, “Fluoride contents in tea and soil from tea plantations and the release of fluoride into tea liquor during infusion”, *Environ. Pollut.*, vol. 104, no. 2, pp. 197-205, February 1999, https://doi.org/10.1016/s0269-7491(98)00187-0.

[67] R. Gautam and N. Bhardwaj, “Bioaccumulation of fluoride in different plant parts of *Hordeum vulgare* (barley) var. RD-2683 from irrigation water”, *Fluor.*, vol. 43, no. 1, pp. 57-60, January-March 2010.

[68] M. Zouari, C. B. Ahmed, R. Fourati, D. Delmail, B. B. Rouina, P. Labrousse, and F. B. Abdallah, “Soil fluoride spiking effects on olive trees (*Olea europaea* L. cv. Chemlali)”, *Ecotoxicol. Environ. Saf.*, vol. 108, pp. 78-83, October 2014, https://doi.org/10.1016/j.ecoenv.2014.06.022.

[69] S. K. Jha, A. K. Nayak, and Y. K. Sharma, “Fluoride toxicity effects in onion (*Allium cepa L.*) grown in contaminated soils”, *Chemosphere,* vol. 76, no. 3, pp. 353-356, July 2009, https://doi.org/10.1016/j.chemosphere.2009.03.044.

[70] K. C. Agarwal, S. K. Gupta, and A. B. Gupta, “Development of new low cost defluoridation technology (KRASS)”, *Water Sci. Technol.*, vol. 40, no. 2, pp. 167-173, July 1999, https://doi.org/10.2166/wst.1999.0113.

[71] N. S. Rao and D. J. Devadas, “Fluoride incidence in groundwater in an area of Peninsular India”, *Environ. Geol.*, vol. 45, no. 2, pp. 243-251, December 2003, https://doi.org/10.1007/s00254-003-0873-3.

[72] S. Ayoob, A. K. Gupta, and V. T. Bhat, “A conceptual overview on sustainable technologies for the defluoridation of drinking water”, *Crit. Rev. Environ. Sci. Technol.*, vol. 38, no. 6, pp. 401-470, September 2008, https://doi.org/10.1080/10643380701413310.

[73] P. Miretzky and A. F. Cirelli, “Fluoride removal from water by chitosan derivatives and composites: A review”, *J. Fluor. Chem.*, vol. 132, no. 4, pp. 231-240, April 2011, https://doi.org/10.1016/j.jfluchem.2011.02.001.

[74] B. Acharya, N. Jyotish, and P. Mohapatra, “Fluoride level in drinking water in Angul district of Odisha and its impact on health: A brief review”, *Int. J. Appl. Dent. Sci.*, vol. 5, no. 1, pp. 231-236, January-March 2019.

[75] P. Renuka and K. Pushpanjali, “Review on defluoridation techniques of water”, *Int. J. Eng. Sci.*, vol. 2, no. 3, pp. 86-94, March 2013.

[76] A. Ramdani, S. Taleb, A. Benghalem, and N. Ghaffour, “Removal of excess fluoride ions from Saharan brackish water by adsorption on natural materials”, *Desalination*, vol. 250, no. 1, pp. 408-413, January 2010, https://doi.org/10.1016/j.desal.2009.09.066.

[77] A. Fadaei, “Comparison of water defluoridation using different techniques”, *Int. J. Chem. Eng.*, vol. 2021, no. 1, pp. 2023895, November 2021, https://doi.org/10.1155/2021/2023895.

[78] S. S. Waghmare and T. Arfin, “Fluoride removal from water by various techniques: Review”, *Int. J. Innov. Sci. Eng. Technol.*, vol. 2, no. 9, pp. 560-571, September 2015.

[79] M. Mohapatra, S. Anand, B. K. Mishra, D. E. Giles, and P. Singh, “Review of fluoride removal from drinking water”, *J. Environ. Manag.*, vol. 91, no. 1, pp. 67-77, October 2009, https://doi.org/10.1016/j.jenvman.2009.08.015.

[80] K. K. Yadav, N. Gupta, V. Kumar, S. A. Khan, and A. Kumar, “A review of emerging adsorbents and current demand for defluoridation of water: Bright future in water sustainability”, *Environ. Int.*, vol. 111, pp. 80-108, February 2018, https://doi.org/10.1016/j.envint.2017.11.014.

[81] S. Chakrabarty and H. P. Sarma, “Defluoridation of contaminated drinking water using neem charcoal adsorbent: Kinetics and equilibrium studies”, *Int. J. Chem. Tech. Res.*, vol. 4, no. 2, pp. 511-516, April-June 2012.

[82] A. Dhillon and D. Kumar, “Development of a nanoporous adsorbent for the removal of health-hazardous fluoride ions from aqueous systems”, *J. Mater. Chem. A*, vol. 3, no, 8, pp. 4215-4228, January 2015, https://doi.org/10.1039/c4ta06147k.

[83] A. Dhillon and D. Kumar, “Nanocomposite for detoxification of drinking water: Effective and efficient removal of fluoride and bactericidal activity”, *New J. Chem.*, vol. 39, no. 12, pp. 9143-9154, September 2015, https://doi.org/10.1039/c5nj01928a.

[84] A. Dhillon, M. Nair, S. K. Bhargava, and D. Kumar, “Excellent fluoride decontamination and antibacterial efficacy of Fe–Ca–Zr hybrid metal oxide nanomaterial”, *J. Colloid Interface Sci.*, vol. 457, pp. 289-297, November 2015, https://doi.org/10.1016/j.jcis.2015.06.045.

[85] S. Meenakshi, C. S. Sundaram, and R. Sukumar, “Enhanced fluoride sorption by mechanochemically activated kaolinites”, *J. Hazard. Mater.*, vol. 153, no. 1-2, pp. 164-172, May 2008, https://doi.org/10.1016/j.jhazmat.2007.08.031.

[86] S. A. Wasay, Md. J. Haron, and S. Tokunaga, “Adsorption of fluoride, phosphate, and arsenate ions on lanthanum-impregnated silica gel”, *Water Environ. Res.*, vol. 68, no. 3, pp. 295-300, May-June 1996, https://doi.org/10.2175/106143096x127730.

[87] Y. Wang and E. J. Reardon, “Activation and regeneration of a soil sorbent for defluoridation of drinking water”, *Appl. Geochem.*, vol. 16, no. 5, pp. 531-539, April 2001, https://doi.org/10.1016/s0883-2927(00)00050-0.

[88] C. Díaz-Nava, M. Solache-Ríos, and M. T. Olguín, “Sorption of fluoride ions from aqueous solutions and well drinking water by thermally treated hydrotalcite”, *Sep. Sci. Technol.*, vol. 38, no. 1, pp. 131-147, January 2003, https://doi.org/10.1081/ss-120016702.

[89] S. K. Swain, T. Patnaik, V. K. Singh, U. Jha, R. K. Patel, and R. K. Dey, “Kinetics, equilibrium and thermodynamic aspects of removal of fluoride from drinking water using meso-structured zirconium phosphate”, *Chem. Eng. J.*, vol. 171, no. 3, pp. 1218-1226, July 2011, https://doi.org/10.1016/j.cej.2011.05.030.

[90] M. Shams, R. N. Nodehi, M. H. Dehghani, M. Younesian, and A. H. Mahvi, “Efficiency of granular ferric hydroxide (GFH) for removal of fluoride from water”, *Fluor.*, vol. 43, no. 1, pp. 61-66, January-March 2010.

[91] Y. Li, S. Wang, A. Cao, D. Zhao, X. Zhang, C. Xu, Z. Luan, D. Ruan, J. Liang, D. Wu, and B. Wei, “Adsorption of fluoride from water by amorphous alumina supported on carbon nanotubes”, *Chem. Phys. Lett.*, vol. 350, no. 5-6, pp. 412-416, December 2001, https://doi.org/10.1016/s0009-2614(01)01351-3.

[92] A. L. Srivastav, P. K. Singh, V. Srivastava, and Y. C. Sharma, “Application of a new adsorbent for fluoride removal from aqueous solutions”, *J. Hazard. Mater.*, vol. 263, pp. 342-352, December 2013, https://doi.org/10.1016/j.jhazmat.2013.04.017.

[93] N. Hamdi and E. Srasra, “Removal of fluoride from acidic wastewater by clay mineral: Effect of solid–liquid ratios”, *Desalination*, vol. 206, no. 1-3, pp. 238-244, February 2007, https://doi.org/10.1016/j.desal.2006.04.054.

[94] W. H. Kang, E. I. Kim, and J. Y. Park, “Fluoride removal capacity of cement paste”, *Desalination*, vol. 202, no. 1-3, pp. 38-44, January 2007, https://doi.org/10.1016/j.desal.2005.12.036.

[95] J. Y. Park, H. J. Byun, W. H. Choi, and W. H. Kang, “Cement paste column for simultaneous removal of fluoride, phosphate, and nitrate in acidic wastewater”, *Chemosphere*, vol. 70, no. 8, pp. 1429-1437, February 2008, https://doi.org/10.1016/j.chemosphere.2007.09.012.

[96] A. K. Gupta, D. Deva, A. Sharma, and N. Verma, "Adsorptive removal of fluoride by micro-nanohierarchal web of activated carbon fibers", *Ind. Eng. Chem. Res.*, vol. 48, no. 21, pp. 9697-9707, April 2009, https://doi.org/10.1021/ie801688k.

[97] X. Zhao, J. Wang, F. Wu, T. Wang, Y. Cai, Y. Shi, and G. Jiang, "Removal of fluoride from aqueous media by $Fe_3O_4@Al(OH)_3$ magnetic nanoparticles", *J. Hazard. Mater.*, vol. 173, no. 1-3, pp. 102-109, January 2010, https://doi.org/10.1016/j.jhazmat.2009.08.054.

[98] S. Kagne, S. Jagtap, D. Thakare, S. Devotta, and S. S. Rayalu, "Bleaching powder: A versatile adsorbent for the removal of fluoride from aqueous solution", *Desalination*, vol. 243, no. 1-3, pp. 22-31, July 2009, https://doi.org/10.1016/j.desal.2008.04.012.

[99] L. Lv, J. He, M. Wei, D. G. Evans, and X. Duan, "Factors influencing the removal of fluoride from aqueous solution by calcined Mg–Al–CO_3 layered double hydroxides", *J. Hazard. Mater.*, vol. 133, no. 1-3, pp. 119-128, May 2006, https://doi.org/10.1016/j.jhazmat.2005.10.012.

[100] L. Chen, H. X. Wu, T. J. Wang, Y. Jin, Y. Zhang, and X. M. Dou, "Granulation of Fe–Al–Ce nano-adsorbent for fluoride removal from drinking water by spray coating on sand in a fluidized bed", *Powd. Technol.*, vol. 193, no. 1, pp. 59-64, July 2009, https://doi.org/10.1016/j.powtec.2009.02.007.

[101] A. Bansiwal, D. Thakre, N. Labhshetwar, S. Meshram, and S. Rayalu, "Fluoride removal using lanthanum incorporated chitosan beads", *Colloids. Surf. B: Biointerfaces*, vol. 74, no. 1, pp. 216-224, November 2009, https://doi.org/10.1016/j.colsurfb.2009.07.021.

[102] D. Thakre, S. Jagtap, A. Bansiwal, N. Labhsetwar, and S. Rayalu, "Synthesis of La-incorporated chitosan beads for fluoride removal from water", *J. Fluor. Chem.*, vol. 131, no. 3, pp. 373-377, March 2010, https://doi.org/10.1016/j.jfluchem.2009.11.024.

[103] N. Chen, Z. Zhang, C. Feng, N. Sugiura, M. Li, and R. Chen, "Fluoride removal from water by granular ceramic adsorption", *J. Colloid Interface Sci.*, vol. 348, no. 2, pp. 579-584, August 2010, https://doi.org/10.1016/j.jcis.2010.04.048.

[104] A. Tor, "Removal of fluoride from an aqueous solution by using montmorillonite", *Desalination*, vol. 201, no. 1-3, pp. 267-276, November 2006, https://doi.org/10.1016/j.desal.2006.06.003.

[105] B. D. Turner, P. Binning, and S. L. S. Stipp, "Fluoride removal by calcite: Evidence for fluorite precipitation and surface adsorption", *Environ. Sci. Technol.*, vol. 39, no. 24, pp. 9561-9568, November 2005, https://doi.org/10.1021/es0505090.

[106] K. Ravikumar and A. K. Sheeja, "Removal of fluoride from aqueous system using *Moringa oleifera* seed cake and its composite coagulants", *Int. J. Curr. Eng. Technol.*, vol. 4, no. 3, pp. 1356-1360, June 2014.

[107] S. Dan and A. Chattree, "Sorption of fluoride using chemically modified *Moringa oleifera* leaves", *Appl. Water Sci.*, vol. 8, no. 2, pp. 1-8, May 2018, https://doi.org/10.1007/s13201-018-0718-6.

[108] A. Tor, N. Danaoglu, G. Arslan, and Y. Cengeloglu, "Removal of fluoride from water by using granular red mud: Batch and column studies", *J. Hazard. Mater.*, vol. 164, no. 1, pp. 271-278, May 2009, https://doi.org/10.1016/j.jhazmat.2008.08.011.

[109] A. A. M. Daifullah, S. M. Yakout, and S. A. Elreefy, "Adsorption of fluoride in aqueous solutions using $KMnO_4$-modified activated carbon derived from steam pyrolysis of rice straw", *J. Hazard. Mater.*, vol. 147, no. 1-2, pp. 633-643, August 2007, https://doi.org/10.1016/j.jhazmat.2007.01.062.

[110] J. Zhang, S. Xie, and Y. S. Ho, "Removal of fluoride ions from aqueous solution using modified attapulgite as adsorbent", *J. Hazard. Mater.*, vol. 165, no. 1-3, pp. 218-222, June 2009, https://doi.org/10.1016/j.jhazmat.2008.09.098.

DOI : 10.31695/IJERAT.2025.7.2

[111] A. Maiti, J. K. Basu, and S. De, “Chemical treated laterite as promising fluoride adsorbent for aqueous system and kinetic modelling”, *Desalination*, vol. 265, no. 1-3, pp. 28-36, January 2011, https://doi.org/10.1016/j.desal.2010.07.026.

[112] S. M. Maliyekkal, S. Shukla, L. Philip, and I. M. Nambi, “Enhanced fluoride removal from drinking water by magnesia-amended activated alumina granules”, *Chem. Eng. J.*, vol. 140, no. 1-3, pp. 183-192, July 2008, https://doi.org/10.1016/j.cej.2007.09.049.

[113] M. Karthikeyan, K. K. S. Kumar, and K. P. Elango, “Conducting polymer/alumina composites as viable adsorbents for the removal of fluoride ions from aqueous solution”, *J. Fluor. Chem.*, vol. 130, no. 10, pp. 894-901, October 2009, https://doi.org/10.1016/j.jfluchem.2009.06.024.

[114] I. B. Solangi, S. Memon, and M. I. Bhanger, “Removal of fluoride from aqueous environment by modified Amberlite resin”, *J. Hazard. Mater.*, vol. 171, no. 1-3, pp. 815-819, November 2009, https://doi.org/10.1016/j.jhazmat.2009.06.072.

[115] K. Biswas, K. Gupta, A. Goswami, and U. C. Ghosh, “Fluoride removal efficiency from aqueous solution by synthetic iron(III)–aluminum(III)–chromium(III) ternary mixed oxide”, *Desalination*, vol. 255, no. 1-3, pp. 44-51, May 2010, https://doi.org/10.1016/j.desal.2010.01.019.

[116] Z. Mustakim, A. Prasetya, and Sarto, “Fluoride removal from wastewater using activated clay: A study kinetics and isotherm adsorption”, *AIP Conf. Proc.*, vol. 2085, no. 1, pp. 020019, March 2019, https://doi.org/10.1063/1.5094997.

[117] S. Mandal and S. Mayadevi, “Defluoridation of water using as-synthesized Zn/Al/Cl anionic clay adsorbent: Equilibrium and regeneration studies”, *J. Hazard. Mater.*, vol. 167, no. 1-3, pp. 873-878, August 2009, https://doi.org/10.1016/j.jhazmat.2009.01.069.

[118] D. P. Das, J. Das, and K. Parida, “Physicochemical characterization and adsorption behavior of calcined Zn/Al hydrotalcite-like compound (HTlc) towards removal of fluoride from aqueous solution”, *J. Colloid Interface Sci.*, vol. 261, no. 2, pp. 213-220, May 2003, https://doi.org/10.1016/s0021-9797(03)00082-1.

[119] S. M. Maliyekkal, A. K. Sharma, and L. Philip, “Manganese-oxide-coated alumina: A promising sorbent for defluoridation of water”, *Water Res.*, vol. 40, no. 19, pp. 3497-3506, November 2006, https://doi.org/10.1016/j.watres.2006.08.007.

[120] A. Goswami and M. K. Purkait, “Removal of fluoride from drinking water using nanomagnetite aggregated schwertmannite”, *J. Water Process Eng.*, vol. 1, pp. 91-100, April 2014, https://doi.org/10.1016/j.jwpe.2014.03.009.

[121] A. Eskandarpour, M. S. Onyango, A. Ochieng, and S. Asai, “Removal of fluoride ions from aqueous solution at low pH using schwertmannite”, *J. Hazard. Mater.*, vol. 152, no. 2, pp. 571-579, April 2008, https://doi.org/10.1016/j.jhazmat.2007.07.020.

[122] M. Yitbarek, K. Abdeta, A. Beyene, H. Astatkie, D. Dadi, G. Desalew, and B. V. Bruggen, “Experimental evaluation of sorptive removal of fluoride from drinking water using natural and brewery waste diatomite”, *Process Saf. Environ. Prot.*, vol. 128, pp. 95-106, August 2019, https://doi.org/10.1016/j.psep.2019.05.052.

[123] D. Mehta, P. Mondal, and S. George, “Utilization of marble waste powder as a novel adsorbent for removal of fluoride ions from aqueous solution”, *J. Environ. Chem. Eng.*, vol. 4, no. 1, pp. 932-942, March 2016, https://doi.org/10.1016/j.jece.2015.12.040.

[124] H. M. Cai, G. J. Chen, C. Y. Peng, Z. Z. Zhang, Y. Y. Dong, G. Z. Shang, X. H. Zhu, H. J. Gao, and X. C. Wan, “Removal of fluoride from drinking water using tea waste loaded with Al/Fe oxides: A novel, safe and efficient biosorbent”, *Appl. Surf. Sci.*, vol. 328, pp. 34-44, February 2015, https://doi.org/10.1016/j.apsusc.2014.11.164.

[125] D. Goswami and A. K. Das, “Removal of fluoride from drinking water using a modified fly ash adsorbent”, *J. Sci. Ind. Res.*, vol. 65, pp. 77-79, January 2006.

[126] M. Malakootian, M. Moosazadeh, N. Yousefi, and A. Fatehizadeh, “Fluoride removal from aqueous solution by pumice: Case study on Kuhbonan water”, *Afr. J. Environ. Sci. Technol.*, vol. 5, no. 4, pp. 299-306, April 2011.

[127] S. P. Kamble, P. Dixit, S. S. Rayalu, and N. K. Labhsetwar, “Defluoridation of drinking water using chemically modified bentonite clay”, *Desalination*, vol. 249, no. 2, pp. 687-693, December 2009, https://doi.org/10.1016/j.desal.2009.01.031.

[128] S. Wang and Y. Peng, “Natural zeolites as effective adsorbents in water and wastewater treatment”, *Chem. Eng. J.*, vol. 156, no. 1, pp. 11-24, January 2010, https://doi.org/10.1016/j.cej.2009.10.029.

[129] W. Nigussie, F. Zewge, and B. S. Chandravanshi, “Removal of excess fluoride from water using waste residue from alum manufacturing process”, *J. Hazard. Mater.*, vol. 147, no. 3, pp. 954-963, August 2007, https://doi.org/10.1016/j.jhazmat.2007.01.126.

[130] A. J. Gadgil and K. Cherukumilli, “Addressing groundwater fluoride contamination using inexpensively processed bauxite”, in *Advances in Water Purification Techniques: Meeting the Needs of Developed and Developing Countries*, 1st ed., S. Ahuja, Ed., Elsevier Inc., Netherlands, 2019, pp. 291-325, https://doi.org/10.1016/b978-0-12-814790-0.00012-0.

[131] Y. Li, P. Zhang, Q. Du, X. Peng, T. Liu, Z. Wang, Y. Xia, W. Zhang, K. Wang, H. Zhu, and D. Wu, “Adsorption of fluoride from aqueous solution by graphene”, *J. Colloid Interface Sci.*, vol. 363, no. 1, pp. 348-354, November 2011, https://doi.org/10.1016/j.jcis.2011.07.032.

[132] B. Kebede, A. Beyene, F. Fufa, M. Megersa, and M. Behm, “Experimental evaluation of sorptive removal of fluoride from drinking water using iron ore”, *Appl. Water Sci.*, vol. 6, no. 1, pp. 57-65, March 2016, https://doi.org/10.1007/s13201-014-0210-x.

[133] C. K. Rojas-Mayorga, A. Bonilla-Petriciolet, I. A. Aguayo-Villarreal, V. Hernández-Montoya, M. R. Moreno-Virgen, R. Tovar-Gómez, and M. A. Montes-Morán, “Optimization of pyrolysis conditions and adsorption properties of bone char for fluoride removal from water”, *J. Anal. Appl. Pyrol.*, vol. 104, pp. 10-18, November 2013, https://doi.org/10.1016/j.jaap.2013.09.018.

[134] S. Ghorai and K. K. Pant, “Equilibrium, kinetics and breakthrough studies for adsorption of fluoride on activated alumina”, *Sep. Purif. Technol.*, vol. 42, no. 3, pp. 265-271, April 2005, https://doi.org/10.1016/j.seppur.2004.09.001.

[135] S. S. Tripathy, J. L. Bersillon, and K. Gopal, “Removal of fluoride from drinking water by adsorption onto alum-impregnated activated alumina”, *Sep. Purif. Technol.*, vol. 50, no. 3, pp. 310-317, July 2006, https://doi.org/10.1016/j.seppur.2005.11.036.

[136] A. Salifu, B. Petrusevski, K. Ghebremichael, L. Modestus, R. Buamah, C. Aubry, and G. L. Amy, “Aluminum (hydr)oxide coated pumice for fluoride removal from drinking water: Synthesis, equilibrium, kinetics and mechanism”, *Chem. Eng. J.*, vol. 228, pp. 63-74, July 2013, https://doi.org/10.1016/j.cej.2013.04.075.

[137] N. Viswanathan, C. S. Sundaram, and S. Meenakshi, “Removal of fluoride from aqueous solution using protonated chitosan beads”, *J. Hazard. Mater.*, vol. 161, no. 1, pp. 423-430, January 2009, https://doi.org/10.1016/j.jhazmat.2008.03.115.

[138] X. Yu, S. Tong, M. Ge, and J. Zuo, “Removal of fluoride from drinking water by cellulose@hydroxyapatite nanocomposites”, *Carbohydr. Polym.*, vol. 92, no. 1, pp. 269-275, January 2013, https://doi.org/10.1016/j.carbpol.2012.09.045.

[139] H. Paudyal, B. Pangeni, K. Inoue, H. Kawakita, K. Ohto, K. N. Ghimire, H. Harada, and S. Alam, “Adsorptive removal of trace concentration of fluoride ion from water by using dried orange juice residue”, *Chem. Eng. J.*, vol. 223, pp. 844-853, May 2013, https://doi.org/10.1016/j.cej.2013.03.055.

[140] Y. Ma, F. Shi, X. Zheng, J. Ma, and C. Gao, "Removal of fluoride from aqueous solution using granular acid-treated bentonite (GHB): Batch and column studies", *J. Hazard. Mater.*, vol. 185, no. 2-3, pp. 1073-1080, January 2011, https://doi.org/10.1016/j.jhazmat.2010.10.016.

[141] J. J. García-Sánchez, M. Solache-Ríos, V. Martínez-Miranda, and C. S. Morelos, "Removal of fluoride ions from drinking water and fluoride solutions by aluminum modified iron oxides in a column system", *J. Colloid Interface Sci.*, vol. 407, pp. 410-415, October 2013, https://doi.org/10.1016/j.jcis.2013.06.031.

[142] M. Sarkar, A. Banerjee, P. P. Pramanick, and A. R. Sarkar, "Use of laterite for the removal of fluoride from contaminated drinking water", *J. Colloid Interface Sci.*, vol. 302, no. 2, pp. 432-441, October 2006, https://doi.org/10.1016/j.jcis.2006.07.001.

[143] E. Tchomgui-Kamga, V. Alonzo, C. P. Nanseu-Njiki, N. Audebrand, E. Ngameni, and A. Darchen, "Preparation and characterization of charcoals that contain dispersed aluminum oxide as adsorbents for removal of fluoride from drinking water", *Carbon*, vol. 48, no. 2, pp. 333-343, February 2010, https://doi.org/10.1016/j.carbon.2009.09.034.

[144] T. Getachew, A. Hussen, and V. M. Rao, "Defluoridation of water by activated carbon prepared from banana (*Musa paradisiaca*) peel and coffee (*Coffea arabica*) husk", *Int. J. Environ. Sci. Technol.*, vol. 12, no. 6, pp. 1857-1866, June 2015, https://doi.org/10.1007/s13762-014-0545-8.

[145] F. Fufa, E. Alemayehu, and B. Lennartz, "Defluoridation of groundwater using termite mound", *Water Air Soil Pollut.*, vol. 224, no. 5, pp. 1552, May 2013, https://doi.org/10.1007/s11270-013-1552-y.

[146] M. Mahramanlioglu, I. Kizilcikli, and I. O. Bicer, "Adsorption of fluoride from aqueous solution by acid treated spent bleaching earth", *J. Fluor. Chem.*, vol. 115, no. 1, pp. 41-47, May 2002, https://doi.org/10.1016/S0022-1139(02)00003-9.

[147] N. Das, P. Pattanaik, and R. Das, "Defluoridation of drinking water using activated titanium rich bauxite", *J. Colloid Interface Sci.*, vol. 292, no. 1, pp. 1-10, December 2005, https://doi.org/10.1016/j.jcis.2005.06.045.

[148] C. E. Choong, K. T. Wong, S. B. Jang, I. W. Nah, J. Choi, S. Ibrahim, Y. Yoon, and M. Jang, "Fluoride removal by palm shell waste based powdered activated carbon vs. functionalized carbon with magnesium silicate: Implications for their application in water treatment", *Chemosphere*, vol. 239, pp. 124765, January 2020, https://doi.org/10.1016/j.chemosphere.2019.124765.

[149] V. Tomar, S. Prasad, and D. Kumar. "Adsorptive removal of fluoride from water samples using Zr–Mn composite material", *Microchem. J.*, vol. 111, pp. 116-124, July 2013, https://doi.org/10.1016/j.microc.2013.04.007.

[150] P. Koilraj and S. Kannan, "Aqueous fluoride removal using ZnCr layered double hydroxides and their polymeric composites: Batch and column studies", *Chem. Eng. J.*, vol. 234, pp. 406-415, December 2013, https://doi.org/10.1016/j.cej.2013.08.101.

[151] J. Wang, W. Xu, L. Chen, Y. Jia, L. Wang, X. Huang, and J. Liu, "Excellent fluoride removal performance by CeO_2–ZrO_2 nanocages in water environment", *Chem. Eng. J.*, vol. 231, pp. 198-205, September 2013, https://doi.org/10.1016/j.cej.2013.07.022.

[152] K. Brindha, R. Rajesh. R. Murugan, and L. Elango, "Fluoride contamination in groundwater in parts of Nalgonda District, Andhra Pradesh, India", *Environ. Monit. Assess.*, vol. 172, no. 1-4, pp. 481-492, January 2011, https://doi.org/10.1007/s10661-010-1348-0.

[153] S. Dubey, M. Agrawal, and A. B. Gupta, "Advances in coagulation technique for treatment of fluoride-contaminated water: A critical review", *Rev. Chem. Eng.*, vol. 35, no. 1, pp. 109-137, January 2018, https://doi.org/10.1515/revce-2017-0043.

[154] F. El-Gohary, A. Tawfik, and U. Mahmoud, "Comparative study between chemical coagulation/precipitation (C/P) versus coagulation/dissolved air flotation (C/DAF) for pre-treatment of personal care products (PCPs)

DOI : 10.31695/IJERAT.2025.7.2

wastewater", *Desalination*, vol. 252, no. 1-3, pp. 106-112, March 2010, https://doi.org/10.1016/j.desal.2009.10.1016.

[155] A. Dargahi, Z. Atafar, M. Mohammadi, A. Azizi, A. Almasi, and M. M. H. Ahagh, "Study the efficiency of alum coagulant in fluoride removal from drinking water", *Int. J. Pharm. Technol.*, vol. 8, no. 3, pp. 16772-16778, September 2016.

[156] M. Tahaikt, R. E. Habbani, A. A. Haddou, I, Achary, Z. Amor, M. Taky, A. Alami, A. Boughriba, M. Hasfsi, and A. Elmidaoui, "Fluoride removal from groundwater by nanofiltration", *Desalination*, vol. 212, no. 1-3, pp. 46-53, June 2007, https://doi.org/10.1016/j.desal.2006.10.003.

[157] A. Mnif, M. B. S. Ali, and B. Hamrouni, "Effect of some physical and chemical parameters on fluoride removal by nanofiltration" *Ionics*, vol. 16, no. 3, pp. 245-253, April 2010, https://doi.org/10.1007/s11581-009-0368-7.

[158] S. Chakrabortty, M. Roy, and P. Pal, "Removal of fluoride from contaminated groundwater by cross flow nanofiltration: Transport modeling and economic evaluation", *Desalination*, vol. 313, pp. 115-124, March 2013, https://doi.org/10.1016/j.desal.2012.12.021.

[159] S. Choi, Z. Yun, S. Hong, and K. Ahn, "The effect of co-existing ions and surface characteristics of nanomembranes on the removal of nitrate and fluoride", *Desalination*, vol. 133, no. 1, pp. 53-64, February 2001, https://doi.org/10.1016/s0011-9164(01)00082-0.

[160] G. L. Amy, B. C. Alleman, and C. B. Cluff, "Removal of dissolved organic matter by nanofiltration", *J. Environ. Eng.*, vol. 116, no. 1, pp. 200-205, February 1990, https://doi.org/10.1061/(asce)0733-9372(1990)116:1(200).

[161] K. Hu and J. M. Dickson, "Nanofiltration membrane performance on fluoride removal from water", *J. Membr. Sci.*, vol. 279, no. 1-2, pp. 529-538, August 2006, https://doi.org/10.1016/j.memsci.2005.12.047.

[162] A. B. Nasr, C. Charcosset, R. B. Amar, and K. Walha, "Defluoridation of water by nanofiltration", *J. Fluor. Chem.*, vol. 150, pp. 92-97, June 2013, https://doi.org/10.1016/j.jfluchem.2013.01.021.

[163] S. J. Wimalawansa, "Purification of contaminated water with reverse osmosis: Effective solution of providing clean water for human needs in developing countries", *Int. J. Emerg. Technol. Adv. Eng.*, vol. 3, no. 12, pp. 75-89, December 2013.

164. S. Dubey, M. Agarwal, and A. B. Gupta, "Recent developments in defluoridation of drinking water in India", In *Environmental Pollution: Select Proceedings of ICWEES-2016*, V. P. Singh, S. Yadav, and R. N. Yadava, Eds., Water Science and Technology Library, vol. 77, Springer Nature, Singapore, pp 345-356, 2018, https://doi.org/10.1007/978-981-10-5792-2_28.

[165] P. I. Ndiaye, P. Moulin, L. Dominguez, J. C. Millet, and F. Charbit, "Removal of fluoride from electronic industrial effluent by RO membrane separation", *Desalination*, vol. 173, no, 1, pp. 25-32, March 2005, https://doi.org/10.1016/j.desal.2004.07.042.

[166] B. Assefa, "Defluoridation of Ethiopian rift valley region water using reverse osmosis membranes", *Zede J.*, vol. 23, pp. 1-6, 2006.

[167] V. V. Gedam, J. L. Patil, S. Kagne, R. S. Sirsam, and P. Labhasetwar, "Performance evaluation of polyamide reverse osmosis membrane for removal of contaminants in ground water collected from Chandrapur district", *J. Membr. Sci. Technol.*, vol. 2, no. 3, pp. 1000117, 2012, https://doi.org/10.4172/2155-9589.1000117.

[168] M. Arora, R. C. Maheshwari, S. K. Jain, and A. Gupta, "Use of membrane technology for potable water production", *Desalination*, vol. 170, no. 2, pp. 105-112, October 2004, https://doi.org/10.1016/j.desal.2004.02.096.

DOI : 10.31695/IJERAT.2025.7.2

[169] M. Grzegorzek, K. Majewska-Nowak, and A. E. Ahmed, “Removal of fluoride from multicomponent water solutions with the use of monovalent selective ion-exchange membranes”, *Sci. Total Environ.*, vol. 722, pp. 137681, June 2020, https://doi.org/10.1016/j.scitotenv.2020.137681.

[170] S. Gmar, I. B. S. Sayadi, N. Helali, M. Tlili, and M. B. Amor, “Desalination and defluoridation of tap water by electrodialysis”, E*nviron. Process.*, vol. 2, no. 1, pp. 209-222, October 2015, https://doi.org/10.1007/s40710-015-0112-4.

[171] M. T. Samadi, M. Zarrabi, M. N. Sepehr, S. M. Ramhormozi, S. Azizian, and A. Amrane, “Removal of fluoride ions by ion exchange resin: Kinetic and equilibrium studies”, *Environ. Eng. Manag. J.*, vol. 13, no. 1, pp. 205-214, January 2014, https://doi.org/10.30638/eemj.2014.025.

[172] G. Patel, U. Pal, and S. Menon, “Removal of fluoride from aqueous solution by CaO nanoparticles”, *Sep. Sci. Technol.*, vol. 44, no. 12, pp. 2806-2826, August 2009, https://doi.org/10.1080/01496390903014425.

[173] E. Bazrafshan, D. Balarak, A. H. Panahi, H. Kamani, and A. H. Mahvi, “Fluoride removal from aqueous solutions by cupricoxide nanoparticles”, *Fluor.*, vol. 49, no. 3, pp. 233-244, July-September 2016.

[174] S. Dubey, A. Singh, B. Nim, and I. B. Singh, “Optimization of molar concentration of AlCl3 salt in the sol–gel synthesis of nanoparticles of gamma alumina and their application in the removal of fluoride of water”, *J. Sol-Gel Sci. Technol.*, vol. 82, pp. 468-477, February 2017, https://doi.org/10.1007/s10971-017-4336-9.

[175] S. Joshi, M. Adhikari (Pradhananga), and R. R. Pradhananga, “Adsorption of fluoride ion onto zirconyl-impregnated activated carbon prepared from lapsi seed stone”, *J. Nepal Chem. Soc.*, vol. 30, pp. 13-23, December 2012, https://doi.org/10.3126/jncs.v30i0.9330.

[176] P. K. Holt, G. W. Barton, and C. A. Mitchell, “The future for electrocoagulation as a localized water treatment technology”, *Chemosphere*, vol. 59, no. 3, pp. 355-367, April 2005, https://doi.org/10.1016/j.chemosphere.2004.10.023.

[177] M. M. Emamjomeh and M. Sivakumar, “Fluoride removal by a continuous flow electrocoagulation reactor”, *J. Environ. Manage.*, vol. 90, no. 2, pp. 1204-1212, February 2009, https://doi.org/10.1016/j.jenvman.2008.06.001.

[178] K. S. Hashim, A. Shaw, R. A. Khaddar, M. O. Pedrola, and D. Phipps, “Defluoridation of drinking water using a new flow column-electrocoagulation reactor (FCER) - Experimental, statistical, and economic approach”, *J. Environ. Manage.*, vol. 197, pp. 80-88, July 2017, https://doi.org/10.1016/j.jenvman.2017.03.048.

[179] M. Sadeghi, A. Fadaei, M. Tadrisi, A. Bay, and A. Naghizadeh, “Performance evaluation of a biological landfill leachate treatment plant and effluent treatment by electrocoagulation”, *Desalination Water Treat.*, vol. 115, pp. 82-87, May 2018, https://doi.org/10.5004/dwt.2018.22263.

[180] A. H. Essadki, B. Gourich, Ch. Vial, H. Delmas, and M. Bennajah, “Defluoridation of drinking water by electrocoagulation/electroflotation in a stirred tank reactor with a comparative performance to an external-loop airlift reactor”, *J. Hazard. Mater.*, vol. 168, no. 2-3, pp. 1325-1333, September 2009, https://doi.org/10.1016/j.jhazmat.2009.03.021.

[181] P. Gwala, S. Andey, V. Mhaisalkar, P. Labhasetwar, S. Pimpalkar, and C. Kshirsagar, “Lab scale study on electrocoagulation defluoridation process optimization along with aluminium leaching in the process and comparison with full scale plant operation”, *Water Sci. Technol.*, vol. 63, no. 12, pp. 2788-2795, June 2011, https://doi.org/10.2166/wst.2011.475.

[182] D. Ghosh, C. R. Medhi, and M. K. Purkait, “Treatment of fluoride containing drinking water by electrocoagulation using monopolar and bipolar electrode connections”, *Chemosphere*, vol. 73, no. 9, pp. 1393-1400, November 2008, https://doi.org/10.1016/j.chemosphere.2008.08.041.

[183] A. Chibani, A. Barhoumi, S. Ncib, W. Bouguerra, and E. Elaloui, "Fluoride removal from synthetic groundwater by electrocoagulation process: Parametric and energy evaluation", *Desalination Water Treat.*, vol. 157, pp. 100-109, July 2019, https://doi.org/10.5004/dwt.2019.24087.

[184] C. S. Luo, W. W. Chen, and W. F. Han, "Experimental study on factors affecting the quality of ice crystal during the freezing concentration for the brackish water", *Desalination*, vol. 260, no. 1-3, pp. 231-238, September 2010, https://doi.org/10.1016/j.desal.2010.04.018.

[185] F. Melak, A. Ambelu, H. Astatkie, G. D. Laing, and E. Alemayehu, "Freeze desalination as point-of-use water defluoridation technique", *Appl. Water Sci.*, vol. 9, no. 2, pp. 34, March 2019, https://doi.org/10.1007/s13201-019-0913-0.

[186] Y. Yang, Y. Lu, J. Guo, and X. Zhang, "Application of freeze concentration for fluoride removal from water solution", *J. Water Process Eng.*, vol. 19, pp. 260-266, October 2017, https://doi.org/10.1016/j.jwpe.2017.05.009.

[187] P. Sahoo and A. Sahoo, "Fluidized bed reactor for treatment of gaseous pollutant: Flourides a case study", *Process Saf. Environ. Prot.*, vol. 103, part A, pp. 259-270, September 2016, https://doi.org/10.1016/j.psep.2016.07.014.

[188] A. K. Swain, A. Sahoo, H. M. Jena, and H. Patra, "Industrial wastewater treatment by aerobic inverse fluidized bed biofilm reactors (AIFBBRs): A review", *J. Water Process Eng.*, vol. 23, pp. 61-74, June 2018, https://doi.org/10.1016/j.jwpe.2018.02.017.

[189] V. L. Dhadge, C. R. Medhi, M. Changmai, and M. K. Purkait, "House hold unit for the treatment of fluoride, iron, arsenic and microorganism contaminated drinking water", *Chemosphere*, vol. 199, pp. 728-736, May 2018, https://doi.org/10.1016/j.chemosphere.2018.02.087.

[190] M. Changmai, M. Pasawan, and M. K. Purkait, "A hybrid method for the removal of fluoride from drinking water: Parametric study and cost estimation", *Sep. Purif. Technol.*, vol. 206, pp. 140-148, November 2018, https://doi.org/10.1016/j.seppur.2018.05.061.

[191] D. Haldar, P. Duarah, and M. K. Purkait, "MOFs for the treatment of arsenic, fluoride and iron contaminated drinking water: A review", *Chemosphere*, vol. 251, pp. 126388, July 2020, https://doi.org/10.1016/j.chemosphere.2020.126388.

[192] X. H. Zhu, C. X. Yang, and X. P. Yan, "Metal-organic framework-801 for efficient removal of fluoride from water", *Microporous and Mesoporous Mater.*, vol. 259, pp. 163-170, March 2018, https://doi.org/10.1016/j.micromeso.2017.10.001.

[193] X. Wang, H. Zhu, T. Sun, Y. Liu, T. Han, J. Lu, H. Dai, and L. Zhai, "Synthesis and study of an efficient metal-organic framework adsorbent (MIL-96(Al)) for fluoride removal from water", *J. Nanomater.*, vol. 2019, no. 1, pp. 3128179, September 2019, https://doi.org/10.1155/2019/3128179.

[194] J. Shen and A. I. Schäfer, "Factors affecting fluoride and natural organic matter (NOM) removal from natural waters in Tanzania by nanofiltration/reverse osmosis", *Sci. Total Environ.*, vol. 527-528, pp. 520-529, September 2015, https://doi.org/10.1016/j.scitotenv.2015.04.037.

DOI : 10.31695/IJERAT.2025.7.2