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Review Article

Comparison of Water Defluoridation Using Different Techniques

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Fluoride pollution in subsurface water is a significant problem for different nations across the world because of the intake of excessive fluoride caused by the drinking of the contaminated subsurface. Water pollution by flouride can be attributed to the natural and human-made agents. Increased levels of fluoride in drinking water may result in the irretrievable demineralization of bone and tooth tissues, a situation called fluorosis, and other disorders. There has long been a need for fluoride removal from drinking water to make it safe for human use. Among the various fluoride removal methods, adsorption is the method most popularly used due to its cheap cost, ease of utilization, and being a scalable and simple physical technique. According to the findings of this study, the highest concentration of fluoride (0.1–15.0 mg/L) was found in Sweden and the lowest (0.03–1.14 mg/L) in Italy. We collected the values of adsorption capacities and fluoride removal efficiencies of various types of adsorbents from valuable released data accessible in the literature and exhibited tables. There is still a need to find the actual possibility of using biosorbents and adsorbents on a commercial scale and to define the reusability of adsorbents to decrease price and the waste generated from the adsorption method. This article reviews the currently available methods and approaches to fluoride removal of water.

1. Introduction

Fluoride is vital in little quantities for bone mineralization and protects against dental caries. Higher intake of fluoride causes teeth enamel decay, called fluorosis (Table 1) [1], and contributes to serious diseases, for example, osteoporosis, brittle bones, arthritis, brain damage, cancer, infertility, fluorosis, Alzheimer syndrome, and thyroid disorder [2, 3]. Fluoride reaches aqueous media by human-made activities, industrial and agricultural activities, and geological sources. All natural sources of water have some level of fluoride. The fluoride levels in the groundwater are related to the kind of minerals (calcium) and rocks [4]. The characteristics of fluoride materials are shown in Table 2. In a few regions of the world, water is brackish and has more than 1.5 mg/L fluoride. It exceeds 5 mg/L in some parts of the world and sometimes reaches 20 mg/L [5]. The challenge of excess levels of fluoride in drinking water is encountered in several parts of the world. At the latest conditions, more than 35 countries across the world have reported high fluoride water sources. India, China, Ethiopia, Kenya, Ghana, Pakistan, Germany, Sri Lanka, Nigeria, Tanzania, Iran, and South Africa are among the most well-known countries with high rates of fluoride on ground. Other countries have reported high levels of fluoride [6]. Some literatures have reported the advantages and limitations of fluoride treatment [6, 7]. For example, reverse osmosis (RO) method has received lots of attention since 1960s owing to enhanced membrane materials and technologies, lower energy consumption, and its ability to segregate practically all total dissolved solids (TDS) from seawater and fulfill guideline standards [8]. The common methods of defluorination have limitations, such as high primary installation cost, defect of selectivity, low capacity, and regeneration or utilization problems [9]. The best fluoride value in drinking water for common good health set by the World Health Organization (WHO) is between 0.5 and 1.5 mg/L at a temperature ranging from 12 to 25°C [10].

A number of potential methods such as chemical adsorption (i.e., precipitation, ion exchange, nanofiltration

Table 1: Effects of drinking water fluoride contents on human health [5].

Fluoride level, mg/L	Health impact
<0.5	Dental caries
0.5–1.5	Optimum dental health
1.5–4.0	Dental fluorosis
4.0–10	Dental and skeletal fluorosis
>10.0	Crippling fluorosis

Table 2: Characteristics of fluoride materials [5].

Material	Chemical composition	Fluorine rate (%)
Fluorapatite	$Ca_3(PO_4)_3F$	4
Bastnaesite	(Ce, La) $(CO_3)F$	9
Cryolite	Na_3AlF_6	45
Fluorite (fluorspar)	CaF_2	49
Villianmite	NaF	55
Sellaite	MgF_2	61

(NF), freeze concentration, RO, electrolysis, dialysis, electrodialysis and electrocoagulation (EC), and fluidized-bed crystallization) and physical adsorption (i.e., bone-char, zeolite, activated alumina, diatomite modified with aluminum hydroxide, nanosorbents, activated bentonite, clay, and activated carbon) have been recommended for the removal of fluoride from drinking water. However, the above absorbents have various limitations, like complicated treatment, low efficiency, and/or a finite functional pH ranges. Various methods have been employed to treat fluoride containing water. However, most are facing challenges, particularly when they should be used in underdeveloped nations. The conventional water treatments like biological techniques are often inefficient to treat chemical materials. Adsorption processes are effective, especially for low levels, and chemical treatments like precipitation and coagulation are costly and generate a relatively high amount of waste or secondary pollutants that require supplementary treatments. Membrane methods are restricted by fouling challenges, and thermal methods are expensive [11]. Each method has its own advantages, limitations, and influencing parameters and works efficiently under best situations. Thus, it is very essential to select the appropriate and effective techniques for removal of fluoride from water sources. The present study aims at presenting a comprehensive review of different defluoridation methodologies for water for pertinent for benchmarking.

2. Methods

This review has principally classified these techniques based on the processes. Databases like Google Scholar, Science Direct, and Web of Science were employed to retrieve several articles on the topic. Keywords like "defluoridation," "fluoride removal," "drinking water," "water treatment," and "groundwater" were added to the previously mentioned methods to retrieve appropriate papers. After a thorough search and removing articles with no direct association with water defluoridation, 113 original articles were primarily contained in the context of the review. This excludes various review papers providing an understanding of different mechanisms of each treatment. The types of waters, such as tap water, brackish water, and groundwater, were investigated in this study.

3. Results and Discussion

Various methods had been employed in these articles, including adsorption (biosorbents, nanoparticles, and bioremediations) (13), ion exchange (1), NF (2), freeze concentration (1), RO (1), electrolysis (1), coagulation (1), metal–organic frameworks (MOFs) (1), and EC (1) (Table 3).

3.1. Adsorption Method. This process has great potential for fluoride removal because of its cost effectiveness, simple utilization, high removal capabilities, and reusability of the adsorbent (regeneration) [6].

Adsorption is controlled by various parameters, such as the temperature, nature of the adsorbate and adsorbent, presence of other pollutants, and experimental status (pH, level of pollutants, exposure time, particle size, and temperature) [4, 12].

Fluoride removal efficiency of industrial origin adsorbents (i.e., hydrated cement, bricks powder, and marble powder) was 80% [13].

In a study, Chen et al. reported the maximum obtained adsorption of fluoride by the Fe–Al granular ceramic to be 96% [14]. One study illustrated that the maximum 93.1% fluoride removal was attained in 50 min using Al/Fe oxide-coated diatomaceous earth [15]. Another study showed that the maximal adsorption capacity of 19.2 mg of F^-/g was achieved using aluminium oxide and manganese oxide [16]. The maximum adsorption capacity of fluoride by using activated alumina was achieved at 1.45 mg/g, pH 7, and the maximum removal capacity of fluoride by fly ash adsorbent was achieved at up to 332.5 mg/g [2]. One study showed that the kaolinite technique removes fluoride at 90%–96% at 120 min [17]. A study by Biswas et al. revealed that heat-activated Mahabir colliery shale (HAMBS550) and heat-activated Sonepur Bazari colliery shale (HASBS550) demonstrate maximum removal of 88.3% and 88.5%, respectively, at primary fluoride level of 10 mg/L, $pH = 3$, and adsorbent quantity of 70 g/L [18].

One study reported that the Mg-hydroxyapatite (HAP) adsorbent developed for fluoride removal from aqueous environments has very good potential for defluoridation with a capacity of 1.4 mg/g. It also found that fluoride removal of 92.34% was achieved with 10 g/L, and equilibrium was reached in 180 min [19]. In another study, AL-Darwish and Abu-Sharar demonstrated that limestone and $Mg(OH)_2$ were used as adsorbents for fluoride removal from aqueous solutions [20]. In a study by Mobarak et al., the maximum adsorption capacity of fluoride was found to be 3.66 mg/g using natural clay modified by decyltrimethyl ammonium bromide and a combination of hydrogen peroxide with decyltrimethyl ammonium bromide [21].

3.2. Precipitation/Coagulation. The method involves the addition of alum salts, lime, and bleaching powder into the conventional water treatment. The basis of the technique is

Table 3: A comparison between the fluoride removal methods.

Process (name of the methods)	Type of environment	Removal performance	Advantages	Disadvantages	Ref.
Adsorption (exhaustive coffee grounds and iron sludge)	Groundwater	Iron sludge 62.92% and exhausted coffee grounds 56.67%	Cheap and easily available adsorbents	Low removal efficiency	[11]
Adsorption (porous starch loaded with common metal ions)	Drinking water	Maximum adsorption capacity of porous starch with Zr (PS-Zr) of 25.41 mg/g	Use of commercial scale	-	[82]
Adsorption (nepheline from alkali-hydrothermal)	Aqueous solutions	Maximum adsorption capacity of 183 mg/g	Cheap adsorbents	High efficiency and adjustment of pH	[83]
NF and RO	Groundwater	Fluoride rejection: 98% for RO and 90% for NF	High efficiency	Membrane fouling, decreased membrane lifetime and chemical persistence, high capital operation and maintenance costs, and hazardous effluent generation	[8, 22]
Ion exchange, membrane filtration, and EC	Aqueous solutions	90%–95%, 99%, and 85.5%	High efficiency	Costly techniques, production of waste, and recommended for small community systems	[2]
Adsorption (purolite A520E resin)	Aqueous environments	64.6%	Good stability and flexibility	Expensive processes	[84]
NF	Groundwater	98%	High efficiency	High capital and running and maintenance costs	[27]
Adsorption (CuO NPs)	Aqueous solutions	97%	High efficiency	–	[42]
Adsorption (Earth modified alumina)	Aqueous solutions	Adsorption capacity of F^-: 26.45 mg·g−1	Easy utilization and high efficiency	Limited yield and long exposure time	[46]
Adsorption (fungus hyphae-supported alumina)	Aqueous solutions	Nearly 90%	Economical and effective technique	Long exposure time	[85]
Freezing temperature	Water solutions	Deionized water spiked with fluoride 85% and salinity 75%	High efficiency and little contamination	More susceptible to the freezing temperature	[73]
Adsorption (diatomite modified with aluminum hydroxide)	Aqueous solution and natural groundwater	89%	Low-cost	Leak of soluble alumina	[86]
Adsorption (zirconium onto tea powder)	Drinking water	Adsorption capacity of 12.43 mg/g	Effective, and safe biosorbent	A slight functional pH span	[87]
Adsorption (activated carbon: banana peel and coffee husk)	Aqueous solution	80% to 84%	Cheap, simple, and environment friendly	Limited efficiency and long exposure time	[88]
Adsorption (single-walled carbon nanotubes)	Aqueous solution	87%–100%	Low cost	Generation of toxic waste	[89]
Adsorption (Mg/Ce/Mn oxide-modified diatomaceous Earth)	Aqueous solution	>93%	Low cost and simple operation	High yield often demands adjustment of pH	[90]
Adsorption (aegle marmelos)	Aqueous solution	52%	Low cost	Low efficiency	[91]
Precipitation/coagulation (lime and alum)	Aqueous solution	-	Simple process and little energy requirement	High cost of maintenance and production of hazardous waste	[1]
MOFs	Aqueous solution	Adsorption capacity of 41.36 mg/g	High surface area and high porous	–	[92]

EC: electrocoagulation; NPs: nanoparticles; NF: nanofiltration; MOFs: metal organic frameworks.

the adsorption of fluoride on the flocs following removal of fluoride. Coagulation is the most cost-effective technique in low-income nations, where societies cannot afford, buy, and use RO for drinking water due to its high primary costs [22].

The precipitation method is seldom used because of its high chemical costs, formation of sludge with a high content of toxic aluminium fluoride composite (alumino-fluoro), being a batch technique, limitation in quantity of water being treated, unpleasant water taste, and high residual aluminium dosage [6]. One of the most common precipitation techniques is the Nalgonda method, which is a means of fluoride removal that depends on the flocculation, sedimentation, and filtration of fluoride with the addition of aluminium sulphate or aluminium chloride and lime. Nalgonda method is preferable at all levels because of its low price and simplicity of handling [23]. Kumar et al. demonstrated the recycled fluoride from acidic liquors of low-grade molybdenite containing alumino silicates [24]. Another study reported that the maximum removal rate of fluoride was achieved at 300 mg/L alum level, in 45 min at $\mathrm{pH} = 6$ [25].

3.3. Nanofiltration (NF). This method appears to be the best method of all membrane techniques for fluoride removal due to the high and special membrane selectivity [6]. Some of the impediments of this method that need enhancement are membrane fouling, inadequate separation and exclusion, chemical persistence, and confined lifetime of membranes [6]. Among several defluoridation methods, NF is an effective technique for water treatment compared with other membrane techniques, for example, RO and electrodialysis (ED) [4]. One study stated that the retention of fluoride anions by NF was in the order of 60% [26]. In a study, Chakrabortty et al. showed that the composite polyamide NF membrane used in the cross flow method was successful in removing 98% fluoride from polluted water [27]. Another study reported that the retention of fluoride by HL membrane exceeds 80% [28].

3.4. Reverse Osmosis (RO). RO is a physical process in which hydraulic pressure beyond the osmotic pressure used to the higher level side of a semipermeable membrane results in a flow of the solvent toward the less thickened side [29]. In their study, Bejaoui et al. reported that the maintenance of fluoride exceeds 90% for both membranes (RO and NF) [9]. Another study demonstrated that a rejection higher than 98% of fluoride was achieved by using the RO membrane [30]. A study by Assefa and Zede revealed that the RO membrane technique removes the fluoride up to the range of 94%–99% [31]. One study reported that the removal percentage achieved by using polyamide RO membrane was 95%–98% [32]. The results of a study revealed that the fluoride removal rate by the RO method varies from 45% to 90% at $\mathrm{pH} = 5.5$ to 7 [23].

3.5. Dialysis and Electrodialysis. Dialysis is based on the diffusion of solutes through the membrane despite utilizing a membrane to retain solutes. Electrodialysis (ED) is an electrochemical segregation of ions that are moved via resin membranes using DC voltage [4]. In their study, Ben Sik Ali Ali et al. showed that the yield of the electrodialysis technique was 86.2% for defluoridation [33]. Another study reported that the fluoride removal efficiency of electrodialysis was from 80% to 90% [34]. The results of a study revealed that electrodialysis technique could remove 50–60% of fluoride within 6 min [35]. One study showed that the fluoride removal efficiency of electrodialysis was from 50% to 90% [36]. Another study claimed that the removal rate of fluoride from drinking water by electrodialysis method was 92% [37].

3.6. Ion Exchange. The resins are expensive and make the treatment uneconomical; however, resins can be regenerated simply. Unfortunately, the regeneration process generates a large quantity of fluoride-loaded waste and disposal is needed for such waste, which is a drawback of this process. However the process efficiency is rather low and powerfully influenced by the presence of other anions (i.e., sulphates, carbonates, nitrates, phosphates, etc.) [6, 34]. Samadi et al. explained that the maximum capacity was achieved 13.7 mg/g at $\mathrm{pH} = 7$ by ion exchange method [38]. Another study reported the maximum fluoride loading of 15.77 g/kg of resin [39].

3.7. Nanoparticles (NPs). Nanotechnology involves the synthesis, development, and specification of nanosized particles (1–100 nm) and has become one of the most active ways of research for purifying polluted water [6].

Among several techniques, nanotechnology has appeared as a potential method for fluoride removal over recent years. The utilization of NPs suggests the potential usage for the polluted water treatment. Some of the distinguished features have demonstrated NPs as superb fluoride adsorbents. These features include high reactivity, small size, excellent catalytic activity, potential reactivity, high surface area, simple separation, and numerous active sites for adsorption. High adsorption qualification, free active valences, and surface energies of NPs have resulted from the previously mentioned features [4].

The maximum perceived adsorption of fluoride by the CaO NPs was 92% within 30 min of exposure time and an adsorbent dose of 0.6 g/L [40]. The study by Jokar et al. has stated that polyaniline/Fe_3O_4 nanocomposite with an elimination capacity of 97.48 and 78.56 mg/g was achieved within 4 h at the optimal pH of 4 and 7, respectively [41].

The fluoride adsorption efficiency of nano-MgO was found to be 90% when using an adsorbent dose of 0.6 g/L [6]. In a study by Bazrafshan et al., the efficiency of more than 89% was observed in fluoride removal where the removal capacity was 357 mg F/g CuO NPs [42]. The maximum adsorption of fluoride by using Al_2O_3/Carbon nanotubes was obtained 28.7 mg/g at pH 6 [43].

The maximum adsorption of fluoride by using $P/\gamma\ Fe_2O_3$ NPs was found to be 99% within 30 min [44]. One study showed that the adsorption capacity of the porous MgO nanoplates was more than 97% in 20 min [45]. The removal of fluoride from aqueous media using lanthanum and cerium modified mesoporous alumina (La/MA and Ce/MA) was studied, and it was found that the maximum adsorption capacity of La/MA was 26.45 mg/g, and the capacity of La/MA was more than Ce/MA and mesoporous alumina [46]. One study showed that the fluoride removal efficiency of the mineral-substituted hydroxyapatite nanocomposite (mHAp) adsorbent is 93% [47]. Another study by Dubey et al. demonstrated that the maximum adsorption of fluoride by using NPs of gamma alumina and alcoholic aluminum chloride was 23 mg/g [48]. Another study showed that the maximum removal of fluoride was achieved at an optimal condition of pH 5.0 and a dose of 1.8 g/L and was found to be 94% using nZVI grafted alumina process [49].

3.8. Bionanocomposites and Carbon-Based Adsorbents.

Bionanocomposites as an effective adsorbent for fluoride removal were developed in recent studies. The biomass from plants, agronomical wastes, and industrial by-products can be used for efficient fluoride uptake, as well as solving their disposal problem [22].

Carbon-based adsorbents have also been studied broadly for fluoride removal as carbon has a high affinity for fluoride anions [50]. One study reported the use of low-cost activated carbon from Pithecellobium dulce carbon for fluoride removal from water and compared it with commercial activated carbon [22]. Ajisha and Rajagopal used pyrolyzed Delonix regia pod carbon for fluoride removal from water. In this method, the maximum removal of 97% was achieved in optimum status [51].

Another study by Bazrafshan et al. demonstrated that fluoride removal capacity for $ZnCl_2$-treated Eucalyptus leaves was 3.5 mgF/g [52]. One study demonstrated that defluoridation capacity for bayerite/boehmite nanocomposites was 56.80 mg/L [53]. The maximum adsorption capacity was 0.75 mg/g using bone-char [2].

Another study reported the feasibility of chitin, chitosan, and lanthanum-modified chitosan as biosorbents for the removal of fluoride from aqueous media [54]. The maximum removal efficiency of fluoride from water was 82.72% using aluminium-impregnated potato plant ash [55]. The optimum defluoridation accomplished at the optimum time of 60 min was 96% using Bermuda grass biosorbent [56].

Raw marine (algae, bivalves, sea star, brittle star, and coral reef) adsorbents are used to remove fluoride from aqueous medium [57]. The efficacy of peel powders of *Ananas comosus* and *Citrus sinensis* to remove fluoride from water was above 90% at pH 6 for *Citrus sinensis* peel powder and above 90% at pH 4 for *Ananas comosus* peel powder for exposure of time for 60 min [58]. The study by Tefera et al. illustrated that the maximum adsorption yield was found to be 86% in 60 min using activated carbon of avocado seeds [59]. Another study reported that a maximum fluoride removal of 85.4% was observed using activated carbon of *Crocus sativus* leaves at the best state of primary fluoride level of 6.5 mg/L and exposure time of 70 min [60]. Another study by Chatterjee et al. found the maximum fluoride removal capacity to be 150 mg/g using carbonized bone meal [61].

3.9. Electrocoagulation (EC).

EC is a simple and a beneficial technique for fluoride removal, but there is a challenge of high turbidity in the purified water. In this method, the availability of electricity has to be ensured, and charge loading has been found to be a vital factor in defluoridation experiments [62, 63]. The EC technique's capability for fluoride removal from industrial wastewater rate was found to be 80% [2]. Another study showed the capability of EC for fluoride removal from tap water to be 90% [64]. In a study, Mureth et al. found the EC technique removal yield to be 90% at the best electrolysis time of 30 min [65]. Another study reported the EC technique removal yield of 96% [66].

In a study by Missaoui on EC treatment for fluoride removal from brackish water, the removal efficiency up to 52% was achieved under optimal status [67]. The study by Chibania et al. reported the fluoride removal of over 85% in 20 min using EC technique [36]. One study indicated that electrochemical technique for defluoridation has shown a good yield for the removal of fluoride and aluminum concurrently using aluminum electrodes under 230 V DC [68]. One study demonstrated that EC technique with iron and aluminum electrodes could favorably remove fluoride from the aqueous media [69]. The study by Graça et al. has demonstrated that continuous EC process can remove 97% of fluoride from 5 L of water with a level of 15 mg F/L [70]. Another study by Betancor-Abreu reported the efficiency of EC treatment for fluoride removal from underground waters, to be up to 85.9% under optimal status [71].

3.10. Freeze Concentration.

This method is effective to remove various organic and inorganic contaminants from industrial sewage/liquid waste and can be used to remove pollutants from water during the formation of ice crystals, particularly in the areas where natural cool energy is available [72]. Freeze desalination techniques possess benefits of low operating temperatures, which minimize scaling and corrosion challenges [11]. The fluoride removal yield of freeze concentration was between 75% and 85% at $-15^{\circ}C$ to $-20^{\circ}C$ [73]. Another study showed that freeze desalination for fluoride removal from tap water was 62% [11].

3.11. Hybrid Methods.

Researchers doing hybrid treatments from the past years have also admired the adsorption and precipitation techniques. Hybrid methods include RO and NF, EC and microelectrolysis, MF and UF, precipitation-adsorption, precipitation/crystallization, MOFs, and EC and floatation. The study by Dhadge et al. demonstrated that a hybrid EC-filtration is capable of removing fluoride from water by 93.2% [74]. Another study reported the maximum fluoride removal with an ultimate fluoride level of 0.43 mg/L using EC-microfiltration hybrid technique [75]. Haldar et al. showed the developments in fluoride removal from drinking water using MOFs [76]. Another study showed that the fluoride adsorption capacity of MOF-801 is 40 mg/L at 303 K [77]. One study stated that the theoretical fluoride adsorption capacity was up to 42.19 mg/L at 298 K using MOF-MIL-96(AL) method [78]. Sandoval et al. reported a removal rate of 73% for EC using a filter-press flow reactor for

Table 4: Amount of fluoride level in groundwater of several nations.

Country	Region/province/city	Fluoride level (mg/L)	Ref.
Ethiopia	South Ethiopian	Shallow wells: 0.5–1.29; deep wells: 0.48–5.61	[93]
Malawi	South Malawi	1.5–6	[94]
Iran	West Azerbaijan	Warm seasons: 0.01–3; cold seasons: 0.01–4	[95]
Iran	Poldasht	0.27–10.3	[96]
India	Peddavagu	0.6–3.6	[97]
India	Telangana	0.4–2.2	[98]
Thailand	Lamphun and Northern Thailand	0.01–14.12	[99]
China	Northern Anhui Province	0.55–2.06	[100]
China	Semiarid	0.11–6.33	[101]
China	Northwestern China	0.12–13.30	[102]
Sweden	Kalmar	0.1–15.0	[103]
United States	–	0.7–4.0	[104]
Italy	Aosta Valley Region	0.03–1.14	[105]
Nigeria	Southwestern Nigeria	Mean:1.23	[106]
Ghana	Upper East Region of Ghana	0.5–4.6	[107]
Mexico	Central region in Mexico	0.56–1.60	[108]
Pakistan	Sindh and Punjab	0.1–3.9, and 0.1–10.3	[109]
Sudan	Tiraat El-Bijah and Um Duwanban	0.45–1.36	[110]
Tanzania	East African Rift	0.5–10	[111]
Argentina	Del Azul Creek basin	Above 1.5	[112]
Benin	Central Benin	1.5–3.02	[113]

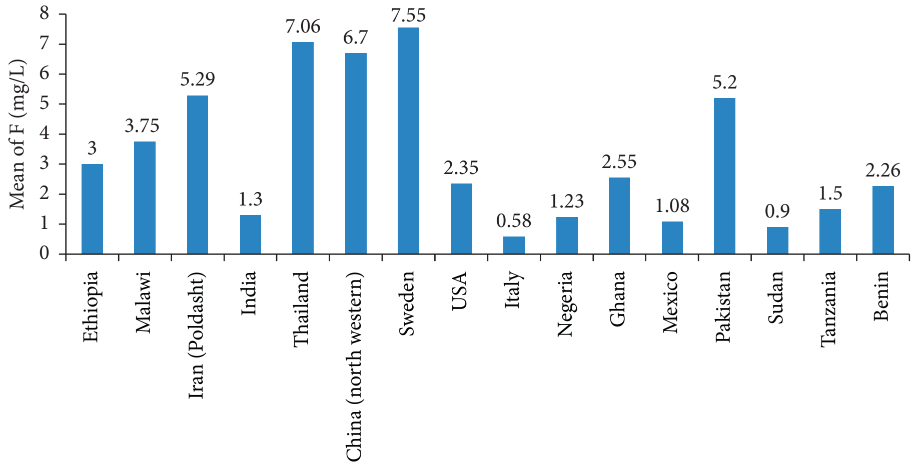

Figure 1: Mean of fluoride level in groundwater of several nations.

fluoride removal from groundwater [79]. One study stated that NF/RO processes were proved to remove both fluoride and NOM from Tanzanian waters [80].

3.12. Worldwide Conditions of Fluoride Concentrations. The largest source of potable water is groundwater, and the majority of the populace use groundwater for potable and agriculture intentions [81]. The highest concentration of fluoride (0.1–15.0 mg/L) was found in Sweden, and the lowest concentration (0.03–1.14 mg/L) was found in Italy (Table 4 and Figure 1). Most of the African countries have regions where fluoride levels are higher than the 1.5 mg/L maximum value recommended by the WHO. In Asia, countries with high fluoride levels in the groundwater and surface water, for example, India and China, are the two most populated and the worst affected, and in North America, some regions in the United States, Mexico, and Canada require water deflouridation because fluorine is present in high levels in the groundwater. In Latin America, Peru, Ecuador, and Argentina possess groundwater with high levels of fluoride. Excess fluoride in groundwater is not a popular challenge in European countries. In some areas of Europe, adding fluoride to drinking water is necessary due to lack of natural fluoride, but some countries, like Spain (Icod de Los Vinos) and Norway (Hordaland), possess groundwater with excess fluoride levels. Apart from Spain, Sweden, and Norway, some districts in Germany also possess high levels of fluoride in their groundwater [81].

The elimination of fluoride by RO and NF is effective, with removal performances of 90% to 99.8%. Limitations of these processes include scaling, fouling, high energy, and fund expenditures. Disadvantages of coagulation with lime and aluminum sulphate were sludge production, high cost, and challenge of final disposal. The removal efficiency depends on raw water pH, coagulant type, coagulant dose, and water composition. Ion exchange is the most effective and extensively used technique with an elimination performance of 90 to 95%. Adsorption is one of the most efficient strategies to remove fluoride from water. In addition, its removal performance is between 56% and 100%. The removal is chiefly based on pH, initial level of pollutant, adsorbent dosage rate, type of adsorbent, flow rate of water, contact time, contaminant solubility, and temperature. The fluoride removal by biosorption process was 52 to 90%. The most important strengths of biosorption include low price, high performance, low production waste, regeneration of biosorbent, being ecofriendly, and possibility of pollutant recovery. In sum, research and development works on fluoride removal from different types of water have advanced considerably, which is required to result in a commercially practicable technique for fluoride removal from different types of water.

4. Conclusions and Future Recommendations

This study explained the adsorption efficiency of a wide range of methods for fluoride removal from water. Various methods were investigated in this research, such as adsorption (biosorbents, NPs, and bioremediations), ion exchange, NF, freeze concentration, RS, electrolysis, coagulation, MOFs, and EC. Adsorption process was the method most commonly used for fluoride removal from water. According to the findings of this study, the highest concentration of fluoride (0.1–15.0 mg/L) was found in Sweden, and the lowest concentration (0.03–1.14 mg/L) was found in Italy.

Future needs include cheap, highly developed systems, with low waste, minimum wastage, and maximum utilization of the accessible waste at the full-scale to continue removal of fluoride. Therefore, the development of new production matters with enhanced physical and chemical characteristics for fluoride and lead removal from aqueous solutions requires high research effort. Defluoridation should be used where there is no other source of safe drinking water. Research into the suggested fluoride removal plans would be valuable for the development of removal methods.

Data Availability

All data generated or analyzed during this study are included within the article.

Disclosure

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Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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