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Research Article

DIFFERENT METHOD FOR REMOVAL OF FLUORIDE FROM CONTAMINATED GROUND WATER: AN APPRAISAL

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Abstract

When the fluoride (F^-) content of drinking water surpasses the allowed limits of 1.5 mg/l, there are health risks for humans, such as skeletal and dental fluorosis, which affects millions of individuals throughout India. More than 19 state in India have endemic situation of fluorosis due to excess fluoride content in ground water. There are various technology for removal of fluoride from ground water. But not any technology is so good enough that remove fluoride contamination of ground water in every situation It has been determined that the choice of treatment method should be site-specific, taking into account local requirements and existing conditions. This is because different technologies have different limitations, and no one process is suitable for all situations.

Keywords: Fluoride, Fluorosis, Ground water, Drinking water, Treatment, Reverse Osmosis (RO), Activated Alumina, Black Carbon, Electro dialysis, India.

INTRODUCTION

We have always believed that water is a free gift from nature that is abundantly available and necessary for maintaining life and the environment. One of the most significant markers of development is the availability of potable water that is pure, which is a fundamental human right. Throughout the world, groundwater is a substantial and reliable supply of drinking water [1]. For a variety of purposes, including drinking, domestic, industrial, and irrigation, the majority of people in India depend on ground water, due to the lack of surface water in the country. Because of this, access to clean drinking water is crucial for the advancement of humankind. [2] Sellaite (MgF2), fluorspar (CaF2), cryolite (Na3AlF6), and fluorapatite [3Ca3 (PO4)2 Ca (F, Cl2)] are the major forms of fluoride. These minerals contain almost no soluble fluoride in water. Fluorides are therefore only found in groundwater when large volumes of fluoride-containing industrial effluent are dumped into water bodies or when favorable conditions are met for their dissolution.

Impact of fluoride on health

Fluoride in drinking water has a substantial impact on teeth and bones. This provides a limited amount of enamel strengthening. However, fluoroapatite is orders of magnitude less soluble than hydroxyapatite, which is the primary component of teeth and bones, except in small amounts. High fluoride concentrations cause a large amount of hydroxyapatite to be transformed into fluoroapatite, which makes teeth and bones more brittle, hard, and denser after prolonged exposure. The term used to describe the mottling and embrittlement that teeth develop is dental fluorosis. Skeletal fluorosis results from extended exposure to increased fluoride concentrations, [3] (Dissanayake, 1991) table-1

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Table 1. Effect of prolonged use of drinking water on human health, related to fluoride content F

F(concentration, mg/L)	F(concentration, mg/L)
<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

As industrial activity grows, water bodies with high fluoride content are becoming increasingly problematic. There are many continent with high groundwater fluoride concentrations up to 30 mg/L including the United States, Africa, and Asia. [4(a) (b) (c)], [5],[6],[7], [8], [9],[10], [11], [12], [13]. It is estimated that over 260 million people globally consume water containing more than 1.0 mg/L of fluoride [14]. Severe dental and skeletal fluorosis is present in over 29 countries, endangering public health and undermining social cohesion. [15–17].

Dental fluorosis

Enamel loses its luster when it is exposed to too much fluoride. When dental fluorosis is minor, it appears as white, opaque patches on the tooth's surface. When it is severe, it can cause symptoms including severe tooth pitting with stains ranging from yellowish brown to black. The quantity of fluoride exposed to teeth until they are 8 to 10 years old determines the extent of dental fluorosis since fluoride stains only the teeth as they are forming in the jawbones and are still beneath the gums.

Skeletal fluorosis

Both adults and children can develop skeletal fluorosis. It takes a long time to become noticeable until the illness reaches a more advanced state. Fluoride, which mostly builds up in the shoulder bones, pelvic, knee and the joints of the neck, makes walking and moving more difficult. The symptoms of skeletal fluorosis are similar to those of spondylitis and arthritis.

Atypical calcium deposits in bones, muscle weakness, burning-like feeling, prickling and tingling in the limbs, back stiffness, and intermittent pain are some of the early symptoms.

Other problem

Because it's widely believed that fluoride primarily affects teeth and bones, this element of fluorosis is frequently ignored. Overdosing on fluoride can result in skeletal and dental fluorosis as well as a host of neurological symptoms, such as depression, gastrointestinal problems, urinary tract problems, nausea, abdominal pain, tingling in the fingers and toes, low hemoglobin levels, abnormalities in RBCs, polydipsia, headaches, dermatitis, anxious, and neurological manifestation(structural, biochemical or electrical abnormalities in brain, spinal cord orother nerves). It also alters the way the kidney, liver, digestive tract, respiratory system, excretory system, central nervous system, and reproductive system function, breaking down about 60 different enzymes in the process. Animals are impacted by fluoride in drinking water in a similar way to humans. Crop growth suffers when high fluoride water is used for extended periods of time.

Flouride content of India's groundwater

India is among the countries most affected by F-contamination of underground water. 48 mg/L to 0.5 mg/L. [18]. There are 12 million to 85 million tons of F-deposits in India on the crust of the earth. Which may be the cause of the high F-occurrence in groundwater. According to Central Ground Water Board (CGWB) in India, dental, skeletal, and non-skeletal fluorosis affects around 95 million people, including 6.5 million children, [19] The CGWB research also notes that high to severe groundwater fluoride pollution affects 223 districts across 23 states reaching up to 45 mg/L [20–31]. It was initially discovered in the Andhra Pradesh area of Nellore in 1937 [32]. The affected states include Andhra Pradesh [33–36], Assam [37], Bihar [38], Delhi [39],Gujarat [40], Karnataka [41-42] Kerala [43], Madhya Pradesh[44-45] Maharashtra [47], Orissa [48-49], Rajasthan [50-51] and Tamil Nadu [52-53]. Rare occurrences of elevated fluoride levels have been documented in alluvial plain groundwater typically exhibit infrequent variations and alterations. With most cases of fluorosis reported in regions containing granite and gneissic formations across various states. Numerous researchers have documented the fluoride content in the Ganga alluvial plain of Uttar Pradesh (UP), and the districts of Varanasi [65], Unnao [66], Kanpur, Agra [67], and Mathura [68] have received acknowledgement from the State and Central Governments (Table 2)...

Table 2. Fluoride content in the underground water of different states of India

Location (mg/l)	Fluoride	Reference
Assam	0.4–20.6	54
Tamil Nadu	0.5-14.0	55
Bihar	0.1–2.5	56
Gujarat	0.1–40	57
Maharashtra	NA	58
Karnataka	0.33–7.8	59
Orissa	0.3–10.1	60
Uttar Pradesh	0.2-2.1	61
Rajasthan	0.1-14	62
Andhra Pradesh	0.6-2.5	63
Delhi	0.2–32.5	64
Madhya Pradesh	1.5–4	65

NA: Not available

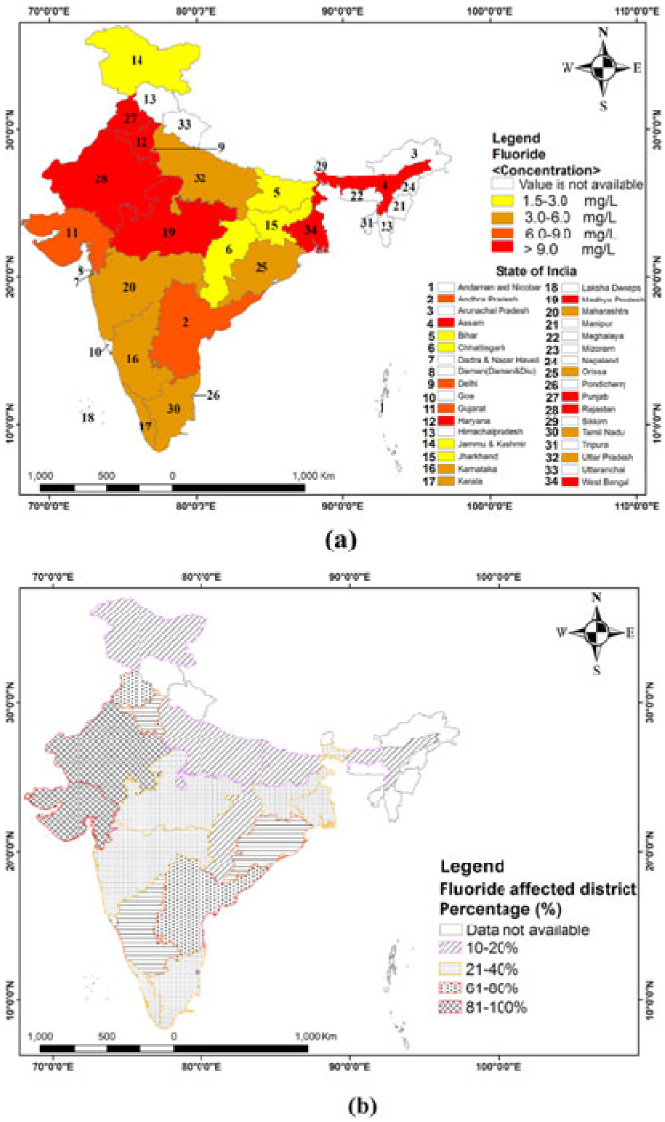

Figure 1. Fluoride concentration (%) in different state of India

Fluoride removal from water

It is essential to lower the fluoride content of potable water to acceptable levels as recommended by international or regionally recognized organizations in order to avoid or reduce negative health effects from fluoride exposure. Since F− contamination of groundwater is common in India, it is crucial to have a comprehensive resource that offers a variety of tactics and approaches to lower the health hazards associated with F−.The following actions can reduce or prevent fluoride poisoning:

- Using different sources of water.
- By eliminating too much fluoride.
- By enhancing the nutritional status of the community that is at risk.

1. Using different sources of water: As alternative water sources, surface water, rainfall, and low-fluoride groundwater can be used. Poor communities cannot afford to use surface water because it is often highly contaminated with chemical and biological pollutants and requires treatment and disinfection before it can be used for drinking. Rainwater typically offers a simpler, less expensive solution and is a far cleaner source of water. Its unequal distribution and limited storage capacity in homes

or communities, however, is the issue. [69] Because fluoride is irregularly distributed in groundwater and changes in concentration over time both vertically and horizontally, it is necessary to test each well separately and conduct routine monitoring, which is not always feasible in rural regions.[70] Therefore, employing alternative water sources has its own set of drawbacks.

2. By enhancing the nutritional status: Clinical evidence suggests that consuming enough calcium is directly linked to a lower risk of dental fluorosis [71]. Additionally, vitamin C reduces the risk [72]. Although improving the nutritional status of a population affected by an issue could be a useful addition to technical remedies, in practice this seems unfeasible.

3. By eliminating too much fluoride: The only workable solution to the issue of too much fluoride in drinking water is to remove it from the water. Several studies have been carried out on F− removal from drinking water when it was discovered that excessive concentrations of F− cause fluorosis.

Numerous methods for removing fluoride from wastewater and water have been well researched. Ion-exchange [77], membrane separation process [77, 78] adsorption [73, 74, 75, and 76], precipitation-coagulation [78, 79], electrodialysis [80–82], electrolytic defluoridation [79], and other principles form the basis of these techniques.

***Adsorption*:**

The process of molecules from a bulk solution adhering to a solid surface through chemical or physical forces is known as adsorption. Through a contact surface, the water enters the adsorption process, where fluoride is removed by ion exchange or a surface chemical reaction with the solid surface matrix. For small populations in particular, adsorption onto a solid surface is a simple, flexible, and effective method of contaminating drinking water systems. Over a large pH range, the adsorption method is more effective at removing ions and leaving behind less residue [83, 84]. A variety of adsorbent materials have been reported in the literature, including activated alumina coated silica gel, activated carbon, activated alumina, carbon, activated, calcite, activated coconut shell powder, activated sawdust, activated fly ash, groundnut shell, bone charcoal, coffee husk, defluoron-1, defluoron-2, rice husk, magnesia, serpentine, tri-calcium phosphate, activated soil sorbent and so forth [84–86]. The most popular adsorbents are activated carbon and activated alumina. The effectiveness of activated alumina in removing fluoride is influenced by hardness and surface loading, which is the ratio of total fluoride concentration to activated alumina dosage. The adsorption process has the potential to remove up to 90% of fluoride, which makes this treatment extremely practical. Every four to five months, the adsorbent needs to be renewed, and each regeneration cycle reduces how well it removes fluoride. Mckee and Johnston's study on the application of powdered activated carbon for fluoride removal yielded excellent results [87] Activated carbon and activated alumina are the most widely used adsorbents. Hardness and surface loading the ratio of total fluoride concentration to activated alumina dosage have an impact on how well activated alumina removes fluoride. Up to 90% of fluoride may be eliminated through the adsorption process, making this treatment incredibly feasible. The adsorbent needs to be replaced every four to five months, and the efficiency of fluoride removal decreases with each regeneration cycle. Excellent results were obtained from Mckee and Johnston's study [87] on the application of powdered activated carbon for fluoride removal.

***Advantages*:**

Operational simplicity.
The adsorption technique is beneficial.
High efficacy in eliminating fluoride, with a 90% elimination rate.
Generate water of superior grade.
It is possible for regeneration.

***Disadvantages*:**

The issue of getting rid of depleted adsorbents and concentrated regenerating materials.

Distinct anions (sulfate, phosphate, or carbonate) in close proximity may cause interference, potentially resulting in struggling for the adsorbent's active sites.

Decrease in removal effectiveness after the renewal stage.
Because the process has poor integrity, a limited capacity for adsorption, and both, pre-treatment is required.

The pH range between 5 and 6 is the only one where the process performs best.

A high concentration of total dissolved salts (TDS) can cause fouling of the alumina bed.

Ion-exchange:

Resin with quarternary ammonium functional groups is a strongly basic anion-exchange resin that can be used to remove fluoride from water after reaction. The following reaction triggers the removal:

$$\text{Matrix- NR3+Cl−+F−} \longrightarrow \text{Matrix-NR3+F−+Cl−}$$

The resin's chloride ions are swapped out for fluoride ions. This procedure keeps going until every place on the resin is filled. Following that, the resin is stir with supersaturated water that is saturated with sodium chloride. The fluoride ions are subsequently replaced by new chloride ions, which recharges the resin and restarts the process. The higher electro negativity of the fluoride ions is what propels the substitution of chloride ions from the resin. In batch and column mode, Chikuma et al. looked into the use of modified anion exchange resin containing lanthanum complex of Alizarian Fluorine Blue and anion exchange resin for the removal of fluoride [88]. Ku et al. looked into the removal of fluoride from water using Duolite C-467 resin that was loaded with aluminum. The pH of the fluoride removal from aqueous solution was found to be relatively constant [89].

***Advantages*:**

Removes 90–95% of the fluoride.
Maintains the water's flavour and colour

Disadvantages:

The technique is very expensive.

The pH of the treated water is low, and it contains a lot of chloride.

Interference brought on by the presence of additional anions such as alkalinity, phosphate, carbonate, and sulphate.

Resin regeneration raises concerns since it produces waste that is high in fluoride and needs to be addressed before final disposal. A longer reaction time is necessary in this method.

Precipitation–coagulation:

The two coagulants that are most frequently used are lime and alum. Lime expansion causes fluoride to precipitate as insoluble calcium fluoride and increases pH to 11 -12.

$Ca\ (OH)_2 + 2F^- \rightarrow CaF_2 + 2OH^-$

Because lime leaves a residual of 8.0 mg F−/L, it is only used in concurrence with alum treatment to enable proper fluoride removal [90–92]. When alum is added to water, there are basically two reactions that happen. Al (OH) 3 insoluble aluminum hydroxide is created in the first reaction when the component of alkalinity and alum come together. In the second reaction, alum and fluoride ions in the water interact. For fluoride removal, a pH range of 5.5 to 7.5 is ideal [93].Coagulation is a precipitation method developed in 1975 by the National Environmental Engineering Research Institute (NEERI), India [94] is known as the Nalgonda technique involves adding lime, bleaching powder, and aluminium salt. This is followed by rapid mixing, flocculation, sedimentation, and filtration. Water that contains fluoride is treated with aluminium salt. The relative fluoride concentration determines the fluoride dosage.Because of its low cost, India uses this technology extensively. Following reactions [95] takes place during Nalgonda technics.

$$Al_2\ (SO4)_3.\ 18H2\ O \rightarrow 2Al^{+3} + 3SO_4^{-2} + 18H_2\ O \quad (1)$$

$$2Al^{+3} + 6H_2\ O \rightarrow 2Al\ (OH)_3 + 6H+ \quad (2)$$

$$F^- + Al\ (OH)\ 3 \rightarrow Al - F \text{ complex} + \text{undefined product} \quad (3)$$

$$6Ca\ (OH)_2 + 12H^+ \rightarrow 6Ca^{2+} + 12H_2\ O \quad (4)$$

Advantages:

The Nalgonda defluoridation method, which combines the use of lime and alum in two steps, is said to be the most efficient way to remove fluoride.

As part of the Rajiv Gandhi Drinking Water Mission, numerous fill and draw (F&D) and hand pump attached (HPA) plants based on the Nalgonda approach have been established in rural areas.

Due of its affordability and efficiency, it is extensively utilized at the community level.

Disadvantages:

Unsuitable for use in areas with heavy fluoride contamination Up to 0.7–1.2 g/L of aluminum sulfate are required in large quantities.

Due to its neurotoxic properties, purified water containing high levels of aluminum might have negative health impacts.

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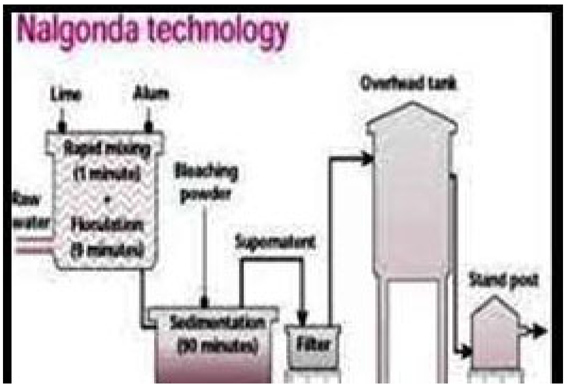

Figure-1 Precipitation coagulation by Nalgonda technology

Membranes separation process:

Membrane approaches involve separating the ions from the water using a semi permeable membrane. It is separated into two primary categories: nanofiltration (NF) and reverse osmosis (RO).

***Reverse Osmosis*:**

In the physical process of reverse osmosis (RO), impurities are eliminated by forcing feed water across a semipermeable membrane. The reverse osmosis system consists of a semi-permeable membrane dividing a tank into two sections. The semi-permeable membrane permits the passage of contaminated water when hydraulic pressure is applied to one side of the tank. While water and some other impurities can pass through the semi-permeable barrier, salts and several other contaminants cannot [96]. Mazighi et al., 2015 [97] used the RO approach to demonstrate the removal of fluoride and discovered that, while taking into account the fact that RO membranes completely regenerate after every set of trials, the amount of fluoride eliminated was greater than 98%. The selection of RO membrane is determined by several parameters, including raw water properties, pretreatment, rejection, recovery, and cost. The pressure, temperature, raw water qualities, and routine maintenance all have a significant impact on the RO system's efficiency. Figure given below

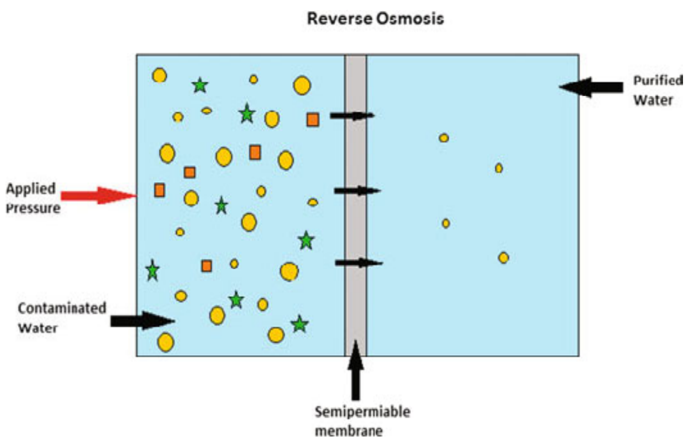

Figure 2. Membrane separation by RO

Nanofilteration (NF):

Water hardness is reduced by nanofiltration, which uses membranes with strong retention capacities for charged particles like bivalent ions. This intrinsic feature makes nanofiltration which has extremely specific membrane selectivity possibly the best membrane method for F-removal. [98] Two commercial nanofiltration membranes, NF-90 and NF-270, were the subject of another experiment [99]. F− concentration was lowered by NF-270 from 10 to 1.5 mg/L, and fluoride concentration was lowered by NF-90 from 20 mg/L to 0.5 mg/L.

Advantages:

- The fluoride removal process is fairly effective. Furthermore, membranes are an effective way to block suspended solids, all inorganic pollutants, organic micro pollutants, pesticides, microbes, etc.
- Water can be treated and disinfected in a single step thanks to this method.
- It guarantees steady water quality.
- Very little upkeep is needed, and no chemicals are needed.
- Because the membrane has a long enough lifespan, regeneration or replacement issues arise less frequently.
- It functions in a broad pH range.
- Not any evidences of additional ions interfering is seen.
- The method uses a compact modular model to operate in a straightforward, dependable automated manner with the least amount of human labor.

Disadvantages;

- All of the ions in the water are eliminated, but since certain minerals are needed for healthy development, remineralization is necessary after using this technique.
- The technique is very costly in contrast to other technique.
- The pH of the water must be adjusted when it turns acidic.
- As brine, a huge amount of water is lost.
- Brine disposal is an issue.

Electrolytic defluoridation

A filtering method called electrocoagulation (EC) reduces suspended particles (such F−) in water to sub-µm levels. [100].In the electrolytic process of electrocoagulation, metallic cations are synthesized at sacrificial anodes upon the application of an electrical charge via an external power source [101]. Electrocoagulation is an efficient method for eliminating various contaminants such as oil, dye, heavy metals, and F- . During the defluoridation process, electrocoagulation preserves beneficial compounds present in raw water and does not generate secondary contaminants. According to Sinha et al. [102], electrocoagulation using aluminum electrodes at 230 V DC was quite effective in eliminating aluminum and F− concurrently. Additionally, longer retention times resulted in improved F− removal from drinking water. This method combines the three basic related processes of electrochemistry, coagulation, and hydrodynamics, which work together to eliminate contaminants.

The following are the primary chemical reactions that take place at the electrodes (aluminum and iron electrodes) during the electrocoagulation process, according to an analysis of those processes. [103]

$$Al\ (s) \leftarrow\text{-}\rightarrow Al(aq)^{+3} + 3e^-$$
$$3H_2O + 3e^- \leftrightarrow 3/2\ H_2 + 3OH^-$$

Additionally, in the bulk wastewater, the Al3+ and OH-ions generated at electrode surfaces combine to form aluminum hydroxide.

$$Al^{+3} + 3OH^- \leftrightarrow Al\ (OH)_3$$

Moreover, the identical chemical processes that take place during the electro coagulation procedure with iron electrodes:

$$Fe(s) \leftarrow\text{-}\rightarrow Fe\ (aq)^{+3} + 3e^-$$
$$3H_2O + 3e^- \leftrightarrow 3/2H_2 + 3OH^-$$
$$Fe^{+3} + 3OH^- \leftrightarrow Fe\ (OH)_3$$

For the most part, the iron hydroxide and aluminum flocs act as metal ion adsorbents and/or traps. They would thereby take them out of the solution. The impact of different operating conditions such as temperature, pH, voltage, hydraulic retention time (HRT), and number of electrodes between anode and cathode plates on removal of fluoride were studied. [104]

Advantage

- Basic, easily operated equipment with low maintenance costs is required by EC.
- Water treated with EC is safe to drink, colorless, and odorless. Since EC primarily contains metallic oxides or hydroxides, it creates low sludge that is quickly settable and easy to de-water.
- More consistently and efficiently separated by filtration is produced by EC.

Disadvantage

- As a result of oxidation, the "sacrificial electrodes" dissolve into wastewater streams and need to be regularly replaced.
- The utilization of electricity may be lavish in numerous spots.
- The EC unit's productivity may be reduced if an impermeable oxide coating forms on the cathode.
- It is necessary for the wastewater suspension to have high conductivity.
- Gelatinous hydroxide may occasionally have a tendency to solubilize.

Electrodialysis

Using electrically charged membranes and an electrical potential difference, electrodialysis is a mass separation technique that extracts ionic species from an aqueous solution and other uncharged components. Ionic components are extracted from aqueous solutions via ion exchange membranes during electro-dialysis, which is powered by an electric current. Similar to reverse osmosis, electro-dialysis uses current rather than pressure to remove ionic pollutants from water. Positively charged cations move toward the cathode and negatively charged (F-) anions toward the anode when an ionic solution, such as contaminated water, is fed through these cells while a potential gradient between the cathode and anode is applied. Benefits from ED include less chemical use and high water recovery.

The electrodialysis method uses an SB-6407 anion exchange membrane to remove fluoride from water. Optimal feed phase pH under Donnan dialysis conditions, which resulted in the highest fluoride transfer. In the absence of mono- and bi-valent ions, there was a greater elimination of fluoride. Electrodialysis was performed on water with a fluoride content of 20.6 mg/L. The fluoride concentration could be lowered to 0.8 mg/L (96% elimination) despite the presence of sulphate and chloride in the actual water sample, which was less than the 1.5 mg/L World Health Organization (WHO) limit. [105]

Advantage

- Inexpensive before and after care.
- Adaptable (seasonal operation).
- Minimal demand for chemicals.
- Elevated water recovery

Disadvantage

- Ionic component separation occurs only.
- Possible H2 production in the electrode rinse.
- Particular energy usage for pumping
- Treatment with concentrates is necessary

Comparison of different techniques for F− removal

Based on the literature analysis, the following conclusions on fluoride removal techniques were drawn:

Although adsorption has shown promise in terms of cost, efficiency, and technology, there is a significant issue with how to dispose of the sludge that is created by this process. Ion-exchange method is very efficient for fluoride removal but it is expensive and the treated water has high chloride content. Coagulation/precipitation method yields a large amount of residue with a high proportion of residual aluminum and is restricted to 33% of F-removal. Although reverse osmosis and nanofiltration are highly expensive and remove certain necessary ions from the water, they are effective in removing fluoride from the water to a higher extent. If the aforementioned issues are taken into account, the electro coagulation approach is suitable for removing fluoride; however, this method requires a constant power source. It is important to highlight that adsorption technology has garnered a lot of interest lately for the purpose of eliminating fluoride, and that adsorbents have demonstrated increased fluoride adsorption capacity. Nevertheless, an adsorbent that performed well in a lab setting might not work in a real-world setting. Thus, choosing the right adsorbent is somewhat challenging. Finally, it is important to remember that no single technique can be applied in all over India because each has its own restrictions and varies in the amount of fluoride and other competing ions in groundwater.

Conclusion

The current global population growth and urbanization have led to a sharp rise in F− contamination in water. Serious health issues have been brought about by the presence of F− in groundwater at levels above allowable limits. India is home to around 12 million of the 85 million tons of F-deposits on the earth's crust, which may be the cause of the high F-occurrence in groundwater. It is apparent that high F− concentrations in groundwater are harmful to human health. The human body's bones, skeleton, and teeth contain approximately 96% of total fluorine (F−). This means that excessive F− levels may occur, which can lead to a number of health problems, including severe gastroenteritis, salivation, anorexia, muscle weakness, stiffness, restlessness, sweating, dyspnea, and tachycardia. Three distinct strategies fall under the category of defluoridation: (a) using alternate water sources; (b) improving nutrition; and (c) defluoridating water. Since it's not always feasible for those living in India to access better nutrition and alternate water sources, defluoridating the water could be the best course of action. According to the review of the literature, a number of techniques, including ion-exchange procedures, precipitation/coagulation, RO, electro coagulation, nanofiltration adsorption, and electro coagulation, have been used to remove F− from water. The processes of electro coagulation, reverse osmosis, nanofiltration, adsorption, and ion-exchange are the most significant ones for removing F− from water. While various compounds can effectively eliminate F− during the precipitation/coagulation process, alum seems to be the most often utilized substance. Furthermore, compared to the traditional precipitation/coagulation process, electrocoagulation produces a lot less waste sludge. Nanofiltration uses less pressure than reverse osmosis (RO), saving energy. However, the cost of nanofiltration membranes is higher than that of RO membranes. Coagulation-precipitation, in contrast to all of the previously discussed technologies, has proven to be an effective way to remove excessive fluoride from drinking water due to its low cost, simplicity of use, high removal capacity.

India is developing country with limited resources hence on ground level defluoridation of water is done only by coagulation -precipitation method.

Challenges and future prospects

In India, groundwater is the main supply of potable water. Groundwater resources in India are severely strained by the country's growing population, which uses them in an unsustainable way. In general, the main factors contributing to F-excess in underground water are thought to be the emergence of F-containing minerals in deep rocks and their reactions with water. Once groundwater contamination occurs, it is challenging to remediate. A significant portion of the impoverished populace in India is ignorant of the F− health hazards associated with drinking water. Nevertheless, local regulatory agencies are not concentrating on remediation even though they are aware of the health risks associated with F-contamination. Large-scale F-treatment is expensive, so communities and local governments should concentrate on community-based treatment programs. It is important to inform and educate the local populace in order to support the provision of appropriate and affordable remedial technology. India faces various F-remediation issues and challenges, such as:

- Lack of awareness and ignorance of F− contamination.
- Lack of knowledge regarding F−'s detrimental effects on health.
- Absence of F− monitoring and regulation systems in groundwater.
- Insufficient regulations and guidelines regarding the F-management of groundwater.

- Absence of clear enforcement of F-contaminated groundwater laws and regulations.
- Large-scale, expensive remedial technology treatment.
- Insufficient cooperation between local communities and agencies responsible for managing groundwater.
- Lack of affordable and locally relevant F− corrective techniques.
- Ignorance of how future climate change may affect F− contamination in groundwater.
- Inadequate healthcare facilities in the impacted areas and a lack of routine examinations by the local health authorities.
- There are no rules or boundaries marking the F-affected risk areas.
- In the future, more effective use of groundwater resources should be combined with affordable, long-lasting, and implementable solutions. The following is a summary of these solutions.
- Developing or redesigning policy options to control F− concentrations in groundwater.
- Acquiring information on groundwater resources through improved database administration, the use of different methods for evaluating recharge, and efficient aquifer mapping.
- The government must suggest standards for the F− content of drinking water;
- Rules pertaining to pollution and contamination of groundwater resources must be strictly enforced.
- Campaigns to raise awareness in the affected communities and educate the populace.
- Creation of healthcare facilities and routine physical examinations
- Establishment of consistent F−-monitoring infrastructure in impacted regions
- The government ought to establish precise standards for designating risk zones such as low, medium, high, and severe risk that contain F− contaminated water.

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