__Review Article__

Fluoride in Groundwater of Chhattisgarh: A Comprehensive Review of Health Impacts on Humans, Mitigation Strategies, and Sustainable Solutions

Abstract

Fluorosis is a slowly progressing and often neglected disease that poses great health challenges by gradually affecting the human body. Although fluoride toxicity is theoretically reversible, such slow progression leaves with few choices of cure for these side effects, making prevention crucial. Inequitable access to safe sources of drinking water has worsened the prevalence of dental fluorosis, especially in regions where the concentration of fluoride in water is high. This review discusses the association between fluoride exposure, dental fluorosis, and skeletal fluorosis, bringing together an elaborate study of the negative effects that fluoride has on the human body. Skeletal fluorosis is one of the conditions that have received much attention lately. It remains the central theme in this study, which provides information about the latest discoveries made on this condition, detailing its prevalence, health effects, and the course it takes. It also reviews the latest developments in the prevention of fluorosis: new and cheap fluoride removal technologies and mitigation techniques. The conclusions are meant to stimulate further studies on the treatments of fluorosis and on ways to provide clean drinking water inexpensively and sustainably. Fluoride contamination of water is driven by geochemical reactions and natural as well as anthropogenic activities. Although fluoride is necessary for health, quantities over 1.5 mg L^{-1} are toxic, and prolonged exposure through water has severe health effects, including skeletal fluorosis and oxidative damage to vital organs such as kidneys, the brain, thyroid gland, and liver. The review shows the need of prevention and intervention while shedding light on the multifaceted impacts from fluoride toxicity. By focusing on fluoride pollution, the article aims at unravelling the burden on human health and global water security in safeguarding human lives.

Keywords- Groundwater, health, fluoride, water, toxicity, fluorosis

1. INTRODUCTION

Fluoride, present everywhere in the Earth's crust, paradoxically stands for beneficial as well as harmful aspects towards human health [1]. While low amounts of fluoride work beneficially toward oral health and prevent dental decay by fortifying tooth enamel, high intakes lead to some serious conditions which range from crippling dental fluorosis, skeletal fluorosis, to debilitating damage in a spectrum of system organs [2]. Its contradictory nature has earned fluoride a constant scientific interest in the realm of public health as well [3]. Most appropriate for regions having fluoride concentrations over safe limits of natural fluoride-rich groundwater, mainly because it contains higher levels across most regions in India, in this case also Chhattisgarh [4].

Fluoride primarily ends up in ground waters through its natural processes by weathering up naturally formed fluoride-rich rock formations, natural leaching within soil, geochemical reactions [5]. However, human activities like industrial emissions, the use of phosphate fertilizers, coal combustion, and mismanagement of waste further aggravated the problem, contaminating surface and groundwater sources. Groundwater is the drinking water source for millions of people residing in rural India, and often exceeds the 1.5 mg/L maximum limit set by the World Health Organization (WHO) [6]. The issue of fluoride contamination is most acute in the state of Chhattisgarh, which is rich in mineral deposits but has large rural populations dependent on groundwater. This is a problem region for safe drinking water supply due to geological factors combined with the inadequacy of infrastructure in the field of water treatment and distribution [7].

The major forms of fluorosis, which is the primary health effect of chronic excessive fluoride exposure, are dental and skeletal fluorosis, characterized as a progressive and irreversible disease [8]. Dental fluorosis results from fluoride interference with enamel mineralization in childhood, affecting discoloration, pitting, and in serious cases, structural damage to the teeth [9]. In skeletal fluorosis, fluoride builds up in bones over time and manifests as stiffness in the joints and bone deformities and, at more advanced stages, severe disabilities [10]. Of course, beyond the visible impacts, chronic fluoride exposure has been shown to be associated with systemic health problems, including neurotoxicity, hormonal disruption, oxidative stress, and damage to vital organs such as the kidneys, the liver, and the thyroid gland [11].

The socio-economic vulnerability of the rural population in Chhattisgarh has exacerbated the health effects of fluoride exposure [12]. Lack of public awareness, inadequate healthcare infrastructure, and a lack of affordable mitigation technologies have enabled the problem to persist and worsen over time [13]. Scientific research, technological innovation, community engagement, and policy support must all be part of a comprehensive approach to solve these challenges [14].

This review aims to provide a detailed analysis of fluoride contamination in the groundwater of Chhattisgarh, focusing on its health impacts, sources, and mitigation strategies. By synthesizing data from recent studies and highlighting case-specific examples from Chhattisgarh, this paper seeks to shed light on the extent and severity of the problem [15]. This paper will discuss different aspects of fluoride toxicity, from its physiological effects and pathways of exposure to the role of oxidative stress in amplifying the harmful outcomes of fluoride. It will especially give special attention to the most recent advancements in fluoride remediation technologies such as biosorption, bioremediation, and phytoremediation, which can be regarded as cost-effective and environmentally friendly options for fluoride removal.

2. SOURCES OF FLUORIDE

The element fluorine, symbol F_2, is part of the periodic table's halogen group. The gas is easily identifiable by its pale yellow-green hue and its corrosive properties. Impressive reactivity and electronegativity characterize it. Like other halides, fluoride is an ion with a charge of −1, and it is formed as a reduced version of fluorine.

The main reasons why there is an excess of fluoride in the environment are natural resources and industrial pollution that are produced by humans. Naturally occurring fluoride-rich rocks and soil interact with water to contribute fluoride to both surface and groundwater. Percolation of water into the earth deteriorates or leaches fluoride-bearing rocks, making groundwater more polluted than surface water. Evaporation, aquifer water retention, and irrigation frequency and duration affect groundwater fluoride levels. Fig.2 shows fluorine concentrations in human body. Diatomic fluorine (F2), a greenish gas, is only produced in pure gaseous form in a few industrial operations due to its high reactivity [16]. The most fluoride-rich waste comes from chemicals, glass, ceramics, coal power stations, semiconductor manufacturing units, electroplating, brick and iron sectors, aluminium smelting facilities, and beryllium extraction operations. Oral hygiene products, medications, cosmetics, gum, and toothpaste are some of the most common ways that fluoride enters the human body [17].

3. PATHS OF FLUORIDE UPTAKE

Medications, foods, water, air, and beauty items are susceptible to absorbing fluoride. Ingested fluoride is most commonly found in water and other foods.

(i) Water

The Earth's crust contains around 625 mg kg^{-1} of fluoride, an ion found in water. The main cause of fluorosis is consuming fluoridated water [18]. Natural water may contain fluoride in various amounts. Groundwater fluoride content depends on aquifers' physical, chemical, and geological properties, soil and rock acidity and porosity, local temperature, well depth, and other chemicals.

(ii) Drug

Fluoride poisoning has been associated with the long-term use of some drugs, like aspirin. Some examples of its uses include curing osteoporosis with sodium fluoride, treating rheumatoid arthritis with niumic acid, and preventing cavities using a fluoride-based mouth rinse [19]. Tooth decay can be prevented by taking fluoride supplements, which are inorganic fluoride found in drinking water, tablets, and other pharmaceuticals.

(iii) Humans

Found that people and animals absorb fluoride and hydrofluoric acid through their skin. Over 99% of circulatory fluoride ends up in teeth and bones [20-21]. After the stomach empties, fluoride is quickly absorbed from the small intestine [22]. Calcium carbonate and a calcium-rich diet reduce fluoride absorption. [23] Sea tissues may absorb hydrogen ions, but no fluoride builds up.

(iv) Foods and Beverages.

Slight concentrations of fluoride are present in nearly all foods. Soil, water, and fertilizers utilized in irrigation and farming constitutes the determining factors of fluoride levels in food. Food and drink absorbed fluoride has a lesser impact on the body than water and soil [24].

(v) Soil

Soil fluoride levels usually fall between 200 and 300 parts per million [25]. Because of its strong solubility in the soil and its interactions with its many constituents, fluoride is difficult to drain from soils [26]. Only 5–10% of soil fluoride is water-soluble [27]. The concentrations rise with depth. Chemical composition, rate of deposition, soil chemistry, and temperature affect inorganic fluorides discharged into the soil.

(vi) Air

Fluorides are dispersed by coal ash, volcanic activity, phosphate fertiliser production, aluminium production, and industrial activities. However, air exposure accounts for a modest portion of fluoride exposure [28]. Industries have higher air fluoride exposure than non-industries. The burning of coal with high fluoride content causes fluorosis, which affects ten million people in China.

(vii) Cosmetic

Common household items including toothpaste, mouthwash, and cosmetics contain fluorides. The manufacturing process of these goods uses raw materials such chalk, talc, and calcium carbonate, which raises the fluoride levels to 800 to 1000 ppm. Boride is added in concentrations ranging from 1000 to 4000 ppm to fluorinated brands [29]. To reduce the likelihood of tooth decay in youngsters, a variety of fluoride-containing products are used.

4. HEALTH EFFECTS

The cumulative amount of fluoride that people take over time determines whether it is beneficial or detrimental to their health. Dental cavities and bone weakening are caused by a fluoride deficiency when the concentration is less than 0.5 mg L−1, while fluorosis is caused by an intake of more than 1.5 mg L−1. Babies, kids, and adults are all at risk for harmful health problems when fluoride levels rise above the acceptable range.

(i) Dental Fluorosis

Too much fluoride consumed when teeth are developing causes dental fluorosis [30]. As a result, the mineral concentration of the enamel decreases and its porosity increases. Too much fluoride in the diet can lead to fluorosis, a disease affecting the teeth. Worldwide, dental fluorosis may impact as many as 70 million individuals, with an estimated 60 million people living in China and India alone, according to a World Health Organization (WHO) research [31].

When teeth and other tissues are still growing and mineralizing, as they are in children under the age of eight, dental fluorosis is common [32]. Because of this disease, tooth discolouration or mottling might occur because the enamel is more susceptible to attacks.

(ii) Skeletal Fluorosis

A pathologic disease known as skeletal fluorosis can develop when a person inhales or consumes excessive amounts of fluoride, which builds up in their bones and joints over time. Bone resorption and changes in bone tissue calcium levels due to high fluoride deposition disrupt bone mineral metabolism [33]. Figure 1 shows the severity of skeletal fluorosis: mild, moderate, and severe.

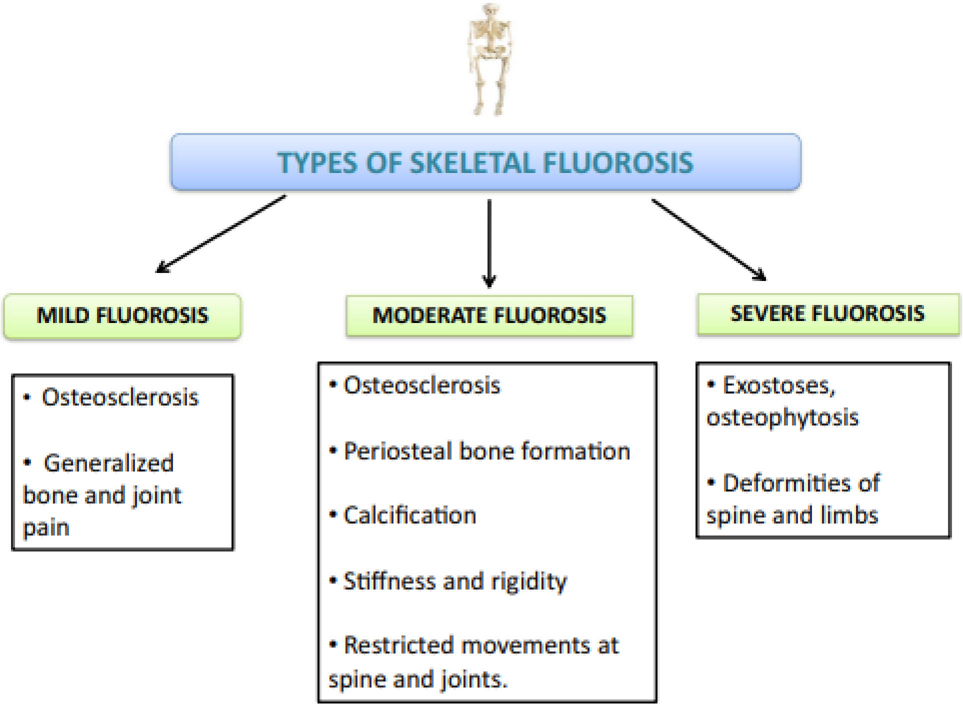

Fig. 1 Types of skeletal fluorosis on the basis of its severity [34]

5. ROLE OF OXIDATIVE STRESS IN SKELETAL FLUOROSIS

Among the several pathways that might set in motion fluoride toxicity, oxidative stress stands out as a potential initiator. The body's antioxidant defense mechanism counteracts the increased ROS activity [35]. Fluoride generates strong hydrogen bonds with -NH and -OH molecules because to its high electronegativity, which boosts its reactivity. Therefore, cancer, aging-related muscle atrophy, fluorosis, and cardiovascular disease are among the chronic disorders that can result from oxidation with different bio-molecules [36].

(i) Neural

At concentrations over 1 mg L−1, fluoride heightens the risk of neurotoxicity, which could impair the ability to learn and remember. Toxicants can cause more damage, and perhaps permanent damage, to the growing brain than to an adult brain. Children residing in locations with high fluoride levels have comparatively inferior mental abilities compared to those residing in areas with low fluoride levels, according to recent research [37].

(ii) Liver and kidney

Histopathological and functional alterations are observed in the kidney, liver, and heart when they are exposed to high fluoride concentrations for an extended period of time. Chronic kidney disease (CKD) is accelerated by the constant consumption of fluoride through food, according to a study [38].

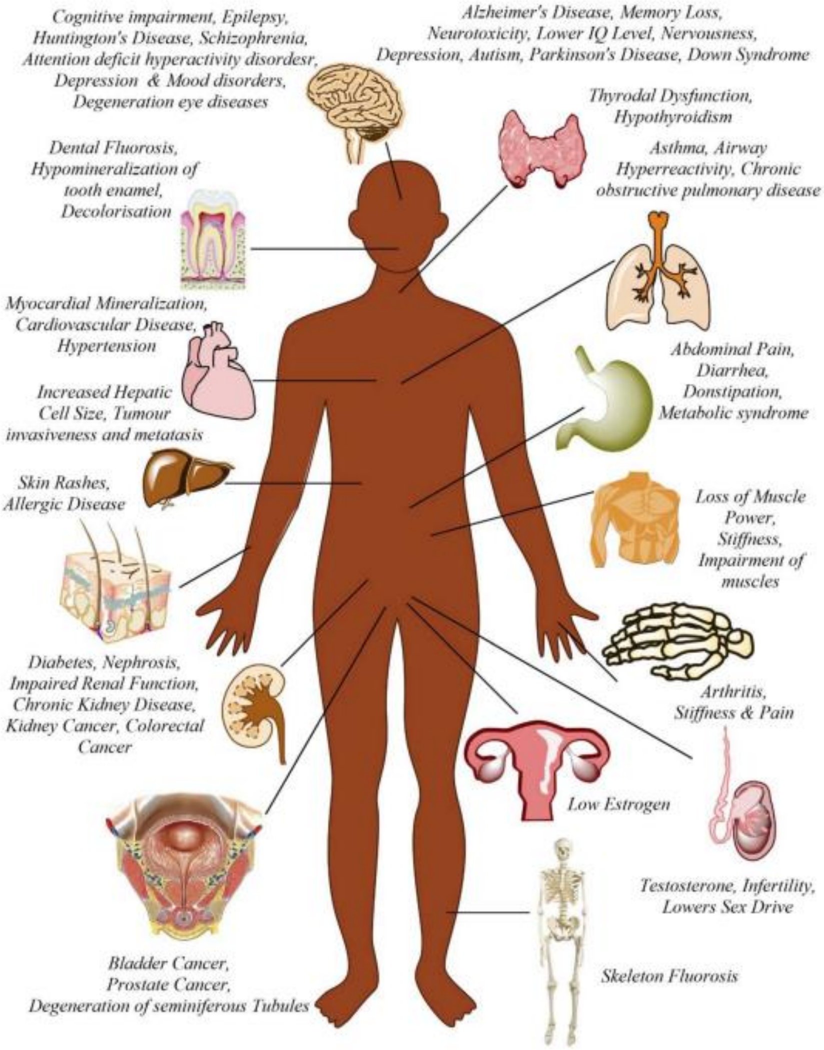

Fig. 2 Effect of fluoride on human body [39]

(iii) Immune system

Fluoride weakens immunity. The study found that NaF reduces silk worm cellular immunity. Lower fluoride concentrations (5 mg L−1) resulted in decreased IL-10 expression by mouse macrophages. Increased fluoride concentrations (50-75 mg L−1) led to increased ROS, Mip

2, and IL-6 levels. The number of macrophages decreased as a consequence of increased lipid peroxidation and redox imbalance.

(iv) Lung

Asthma and fluorosis are common among aluminium sector workers. The majority of fluoride pollution in plants comes from the aluminium and phosphate production processes [40].

(v) Reproductive

At present, infertility is becoming an increasingly pressing global concern, with fluoride being identified as a major contributing component. Increased fluoride exposure is linked to raised LH and FSH, attenuated TH, reduced EL, and an unbalanced ER/AR [41]. Rats with osteoporosis had a 33% decrease in fertility and changes in the shape, density, and metabolism of their spermatozoa. A lower concentration of testosterone in the blood was revealed in a male patient with skeletal osteoporosis.

(vi) Carcinogenic

An epidemiological survey on chronic fluoride disclosure's carcinogenicity had many issues. The biggest issue is cancer, which is detected annually or decades after people enter and exit the study zone and are exposed to pertinent elements. Researchers have considered the idea that fluoride causes bone cancer because it accumulates in the bones [42].

(vii) Renal

Since it excretes most fluoride, the renal system is more vulnerable to high fluoride concentrations [43]. Additionally, research shows that it is more fluoride-sensitive than other tissues. Only two investigations have shown that chronic fluoride consumption can cause kidney stones and non-carcinogenic consequences.

(viii) Hair and Fingernails

It is common practice to evaluate the body's total fluoride load by measuring fluoride in the hair and nails. Damaged fingernails indicate high fluoride levels, even if they only show signs of exposure during the past three to six months, which are known as short-term biomarkers. Current biomarkers, such as hair and nail thickness, are being discussed in various papers in the literature, along with their susceptibility to high fluoride concentrations. At first, pins were proposed as a biomarker [44].

(ix) Endocrine

Although it is hard to interpret, fluoride affected normal endocrine function and reactivity in animals and humans. Fluoride reduces thyroid function, increases calcitonin and parathyroid activity, causes secondary hyperparathyroidism, and lowers glucose tolerance in type II diabetes [45-46]. These effects vary from person to person, and most are subclinical and do not harm human health.

(x) Gastrointestinal

The gastrointestinal symptoms of acute fluoride poisoning, including diarrhoea, vomiting, nausea, and stomach pain, have previously been documented. In animals, fluoride increases gastric acid production, lowers blood flow away from the stomach lining, and kills gastrointestinal tract lining cells [47].

6. CONTAMINATION IN GROUND WATER

The natural and inevitable pollution of groundwater with fluoride has become one of the most significant global challenges. According to reports, two primary factors—geogenic and anthropogenic—contribute to this contamination.

(a) Geogenic source

Average fluoride levels in Earth's crust, observed in various rocks, are 625 mg kg−1. 64 Multiple geological mechanisms raise groundwater fluoride levels. Geological activities such geothermal springs, volcanic eruptions, tectonic movements, weathering, and others can pollute fluoride [48]. Ions like chloride and phosphate increase water fluoride, but calcium decreases it. Using carbon (C), oxygen (O), and hydrogen (H) isotopes, researchers have studied how water is created from evaporation. Aquifer interconnections and climate's effect on fluoride content were also found [49]. According to extensive research, most people drink dirty groundwater, which contains fluoride.

(b) Anthropogenic sources

Human activities including phosphate fertilisers, rodenticides, fumigants, herbicides, and insecticides can raise groundwater fluoride [50]. Coal combustion, fly ash, and tile, steel, aluminium, and glass fluoride particle emissions are other sources of fluoride contamination. Fluoride is mostly produced by burning coal, using phosphate fertilisers in agriculture, and manufacturing cement. Semiconductors, coal power stations, and aluminium processors produce fluoride-rich wastewater. Fluoride concentrations in industrial effluents are 10–1000 times greater than in natural water [51].

7. DEFLUORIDATION THROUGH BIOLOGICAL MEDIATORS

(i) Biosorption.

Microbial treatment or biosorption of F− has emerged as a practical, cost-effective, and environmentally friendly substitute for conventional dehumidification methods due to the limitations of these treatments. Agricultural commodities, bacteria, algae, and fungus are some of the many types of skeletal fluorosis adsorbents developed for use in groundwater defluoridation [52]. Biosorption is how organisms, be they living or non-living biomass, are able to remove heavy metals, pollutants, or contaminants from water or other solutions into the biomass from which they are derived. It is based on the ability of biological substances to adsorb and accumulate the contaminants through the various mechanisms, either by ion exchange and complexation, adsorption, or precipitation. This, therefore, brings biosorption as a not harmful and more economical alternative to the conventional techniques of removing toxins such as chemical precipitation and ion exchange.

The biosorption process usually relies on the presence of functional groups such as hydroxyl, carboxyl, amino, or phosphate groups on the biosorbent material. These functional groups interact with target contaminants so that they may get attached to the biosorbent. Heavy metals include lead, cadmium, chromium, and mercury. Organic pollutants like dyes and pesticides are also removed efficiently by biosorption.

Advantages of biosorption include low-cost, renewable materials, minimal secondary pollution, and the possibility of recovering valuable metals. The process is effective over a wide pH range and even in dilute concentrations. Further research in biosorption focuses on optimization of the process, the development of new biosorbents, and scale-up for industrial applications.

(ii) Bioremediation.

The bioremediation of F− employing specific bacterial strains is still in its early stages [53]. Certain bacterial species can withstand larger F− dosages through bioaccumulation and biotransformation processes. Bioremediation is the process, which is nonintrusive and natural. It involves the use of microorganisms, plants, fungi, or their enzymes to degrade harmful pollutants and contaminants in the environment. Bioremediation is relatively inexpensive as well as an environmentally friendly technology for cleaning polluted soils, water, and air. The biodegradation relies on the fact that some biological organisms can metabolize contaminants to form less toxic or harmless products, such as carbon dioxide, water, or biomass.

In situ and ex situ are the two types of bioremediations, whereby in situ implies treatment at the contaminated site while ex situ treatment involves removing contaminated material and conducting the treatment offsite. Examples of methods involve bioaugmentation, which entails the addition of specific microorganisms to increase the rate of degradation of the pollutants, and biostimulation, whereby nutrients or oxygen are introduced to stimulate action from native microorganisms. Other methods include plants used to absorb and store or degrade contaminants within the plant structure through phytoremediation.

Bioremediation is effective in managing a wide range of pollutants, such as oil spills, heavy metals, pesticides, and industrial wastes. Its benefits include causing minimal environmental disruption and the possibility of targeting specific contaminants. Its success depends on the temperature, pH, and availability of appropriate microorganisms or plants. It is extensively researched for increasing efficiency and widening its industrial and environmental applications.

(iii) Phytoremediation.

Phytoremediation cleans polluted soils cheaply. According to Agarwal and Chauhan [54], Hordeum vulgare diversity RD 2052 leaves exhibited the maximum bioaccumulation of F^- at 9.948 mg kg^{-1}, while the grains had the lowest at 6.302 mg kg^{-1} after exposure to 18 mg kg^{-1} NaF. Phytoremediation is an environmentally friendly method that uses plants to remove, degrade, or contain harmful pollutants from soil, water, and air. This natural process leverages the unique ability of plants to absorb, store, or break down contaminants through their roots, stems, and leaves. Phytoremediation is particularly effective in addressing pollution caused by heavy metals, pesticides, petroleum hydrocarbons, and industrial waste.

There are different types of phytoremediation based on the mechanism involved. Phytoextraction involves plants absorbing contaminants (such as heavy metals) from the soil and storing them in their biomass. Phytodegradation occurs when plants break down organic pollutants into less harmful substances through metabolic processes. Phytovolatilization involves plants absorbing pollutants and releasing them into the atmosphere in a modified form. Rhizofiltration uses plant roots to filter and remove contaminants from water, while phytostabilization immobilizes pollutants in the soil, preventing their spread.

Phytoremediation offers several advantages, such as being cost-effective, aesthetically pleasing, and sustainable. It requires minimal equipment and avoids the need for harsh chemicals. However, it has limitations, including being time-intensive and less effective for highly toxic or deep-seated contaminants. Ongoing research focuses on engineering plants and optimizing conditions to enhance the efficiency of phytoremediation.

8. SUSTAINABLE TECHNOLOGIES FOR THE REMOVAL OF FLUORIDE

The lack of accessible, safe drinking water is a major problem in many parts of the world today. The objective was to ensure that everyone has access to clean drinking water and cut the "environmental sustainability" in half by the year's end 2015. The sixth UN Sustainable Development Goal (UNSDG) in this instance was to ensure that all 2.8 billion people have access to clean water by 2030. Due to their concern about its high impact, developing nations have identified a minimum viable option for fluoride removal [55]. To avoid dental decay, a topic of debate and concern, the World Health Organization has set a minimum fluoride concentration level in drinking water of 1 mg L−1.

The qualities that are specific to fluoride treatment indicate that it is mostly reliant on incineration and landfill disposal. Nonetheless, such approaches ultimately necessitate additional research and development because they do not ensure complete containment and instead reintroduce the pollutant in a different manner. Modern techniques are to blame for the reversal of the entry into the background speed. Research is a crucial and ongoing obstacle to sustainability due to the fact that fluoride recovery is currently technically and practically constrained. The fast increase in waste volume in emerging nations has made it clear that the disposal mechanism is not a sustainable component [56].

9. DISCUSSION

There is some evidence that fluoride can help reduce dental caries, but there are also serious risks associated with it, including cognitive impairment, hypothyroidism, fluorosis of the teeth and bones, imbalances in enzymes and electrolytes, and even uterine cancer. Ingesting or inhaling fluoride, in whatever form, poses an unacceptable danger with almost no demonstrated benefit since the majority of fluoride's hazardous effects occur when the mineral is consumed, whereas the majority of its positive effects occur when the mineral is applied topically [57]. To lessen the likelihood of fluoride exposure in the workplace and the environment, health and safety regulations should be tightened and fluoride waste should be disposed of in a more secure manner. Water fluoridation, whether natural or artificial, poses a threat to public health because, although the effects are most pronounced at high fluoride levels, they are still discernible at lower concentrations in artificially fluoridated water [58]. Furthermore, fluoride has significant negative consequences on human health, and drinking water is a particularly ineffective method of applying it to teeth because of its topical action. The major public health concern concerning fluoride should be reducing ingestion from tea, cereals, and sauces rather than adding it to water or food. Even though artificial fluoridation of water supplies has been a controversial public health strategy since its introduction, highly regarded academics and scientists have struggled to publish critical articles on community water fluoridation in scholarly dental and public health journals.

There would be an inherent bias in favor of fluoridating water supplies if one were to evaluate the literature on public health and dental health. Academics in the field of dental public health have actively worked to portray those who disagree with water fluoridation as being either insane or uninformed [59-60]. Portland, Oregon, USA, citizens rejected fluoridation of their water supply for the fourth time in 2013. Those in charge of public health had an intriguing reaction, painting water fluoridation's detractors as ignorant and insensitive to the needs of low-income groups. .

10. FUTURE PERSPECTIVES

Fluoride is nontoxic in tiny doses but harmful in big doses taken orally over time. Fluoride harm is a global public health issue. Research suggests fluoride disrupts neurotransmission, coagulation, glycolysis, and oxidative phosphorylation. Fluorosis impacts millions worldwide. Severe skeletal fluorosis causes pain and disabilities. Even though fluorosis has no cure, eliminating the source of fluoride can reverse its effects. A diet rich in antioxidant-rich protein, calcium, vitamins, and the like has certain benefits. The condition can be remedied with antioxidant antidotes with low side effects. Antioxidants have become essential to treatment strategies because fluoride is such an oxidiser. Lack of awareness and expensive treatment make large-scale skeletal fluorosis prevention difficult. Research should focus on easy, inexpensive techniques to heal skeletal fluorosis or remove it from water. Since its widespread adoption as a public health approach in the 1950s, fluoride has been evaluated more carefully as a caries prevention method. The review concludes that fluoride's known and unknown health risks exceed its tiny tooth decay prevention benefits. Given its widespread use, fluoride is found in numerous foods, drinks, and airborne particles. Epidemics by Hippocrates explains the ethical principle of disease control. Primum non nocere—"do good or do no harm,"—was emphasised. Given the known and possible hazards of fluoride, this notion is at best partially followed in fluoridation therapies to prevent dental cavities. Due to the health risks of fluoride-contaminated water, water management and environmental preservation must be highly efficient. Since humans put fluoride into the environment, eating and drinking fluoride-containing foods and water is the main health risk. The mandatory UNSDG guide for clean drinking water shows a practical, efficient, and cost-effective fluoride elimination method. This strategy avoids major issues. A process that is deemed appropriate in one place could not meet the requirements in another. As a result, natural water treatment should be used to assess all methods. Communities and local governments should so prioritize treatment strategies that are centred in the community. To help create suitable and affordable healing technologies, local populations should be educated and given notice. In order to effectively reduce fluorosis, it is essential to defluoridate water and reduce fluoride consumption.

11. CONCLUSION

Fluoride poisoning threatens human and environmental health in many countries since groundwater is the only source of drinking water. Fluoride is useful in small amounts but harmful in large doses. High doses can cause tooth and bone fluorosis, nervous system damage, and systemic disorders. Therefore, there needs to be collaboration across fields, creative thinking in science, community involvement, and policy backing from the government in order to reduce fluoride contamination. High prices, technical limitations, and a lack of knowledge in low-resource situations prevent the widespread application of defluoridation technologies such as adsorption, ion exchange, and reverse osmosis. Before implementing sustainable solutions on a large scale, these obstacles need be removed. As part of this process, it is important to identify potential sources of fluoride and eliminate or greatly reduce exposure to such sources. This can be done in conjunction with therapy efforts. There are many different aspects to the difficult subject of fluoride pollution of groundwater. The growing dependence on groundwater poses significant risks to public health, necessitating comprehensive approaches to addressing fluoride poisoning through the integration of new scientific knowledge, policy backing, and community involvement. Addressing these difficulties would pave the way for a healthier and more sustainable future, where everyone has access to safe drinking water.

12. DECLARATION

Authors does not have anything to disclose related with this paper.

13. DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that generative AI technologies such as Large Language Models, etc. have been used during the writing or editing of manuscripts. This explanation will include the name, version, model, and source of the generative AI technology and as well as all input prompts provided to the generative AI technology.

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