ARYAVART SHODH VIKAS PATRIKA
RNI TITLED NO. UPBIL04292
RNI REG. NO. UPBIL/2014/66218
PP. No.- 17-23
ISSN NO.-2347-2944 (Print)
e-ISSN NO.-2582-2454 (Online)
Vol.-16, No.- IV, Issues-30, YEAR- Oct.-Dec.-2023

Fluoride Distribution, Health Risk And Adsorbent Remediation Study of Ground Water of District - Jalaun, Uttar Pradesh

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Abstract: ***Fluoride contamination has created a drinking water crisis globally. At low concentrations, its presence is essential; however, it becomes toxic to human beings upon consumption of more than 1.5 mg L-1 in mainly contaminated drinking water due to geochemical reactions and geological or anthropogenic factors. To better understand the toxicity of fluoride, in this study, we examine the recent research on the possible negative consequences of excess fluoride on diverse species. A high fluoride concentration in drinking water cause skeletal flurosis and long-term kidney, brain, thyroid, and liver damages. This review also focuses on the different techniques for the defluoridation of water, such as electro coagulation, adsorption, membrane processes, etc., and compares their adsorption capabilities under various situations, while their changes in the literature are reviewed. Furthermore, we present the advantages and disadvantages of different methods and conclude that each technique has shortcomings, with no single approach fitting all aspects. The condition of water pollution with fluoride and recently created technology to remove fluoride from water is evaluated, although research on fluoride contamination of water resources has been reviewed in the literature. Alternatively, this study also examines fluorsis mitigation strategies in the global and Indian settings and existing physicochemical and biological mitigation approaches. Also, the research and development results in fluoride clean-up are reviewed. Specifically, the following topics will be covered in this review: (1) fluoride contamination status, (2) consequences of fluoride contamination in drinking water on human health, and (3) current defluoridation technology.***

Key Words: Fluoride contamination, concentrations, geochemical reactions, anthropogenic factors, fluoride.

Drinking water scarcity is now a global challenge in urban and rural areas, where more than 1.5 billion people directly depend on groundwater for drinking purposes worldwide. In the last few years, groundwater has been considered to meet domestic needs and agricultural and industrial requirements, resulting in a drastic change in the chemical composition of underground water. Pollutants originating from various sources can be classed as organic, inorganic, bacteriological, etc., which a enter aquifers, creating a drinking water crisis. The World Health Organization (WHO) considers that fluoride is one water contaminant, adversely affecting human health. Drinking water is measured as the critical fluoride carrier in the human body, where the digestive system absorbs 90% of the fluoride intake through water.

Some rocks such as fluorite, biotite, topaz, fluorapatite, cryolite hornblende, and muscovite contain fluoride-rich minerals, which release fluoride present in them after inter-acting with water. The fluoride ion concentration available in groundwater is dependent on various factors, which include the physiochemical condition of the aquifer from where the groundwater is extracted, intensity of rock weathering, depth of water in the aquifer, acidity and porosity of soil and rocks, interaction between deferent chemical elements, temperature in the surrounding region, mineral composition of rocks, and the geochemistry of the groundwater. In arid and semi-arid regions, the concentration of fluoride in the groundwater is maximum. However, most of the world's groundwater is observed to cross the fluoride concentration standard limit, as suggested by the WHO. According to the WHO guideline, the concentration of fluoride in drinking water should be in the range of 0.5 to 1.5 mg L-1, which is generally safe. However, the amount may vary between 0.5 to 1.0 mg L-1 depending on climatic variables such as temperature. Regarding the two climatic conditions, hot and cold climates, the maximum fluoride concentration suggested by the WHO is 1 and 1.5 mg L-1, respectively, which accounts for the higher water consumption in the hotter climate than in the colder weather. The national standard limit that meets the maximum fluoride value in drinking water is reported to be 1.0 mg L-1. If the fluoride level crosses the limit of 1.0 mg L-1 by any means, either anthropogenic or geogenic sources, the groundwater will be classified as fluoride-polluted groundwater. In our country, the practical limit for fluoride in drinking water is recognized to be 1 mg

L-1. However, the concentration range of fluoride in drinking water varies according to different organizations such as the WHO, Bureau of Indian Standards (BIS), Indian Standard Institution (ISI), Indian Council of Medical Research (ICMR), and others, as listed in Table S1. It has been observed that a large portion of the population globally (mainly >200

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ISSN NO.-2347-2944 (Print)
e-ISSN NO.-2582-2454 (Online)
Vol.-16, No.- IV, Issues-30, YEAR- Oct.-Dec.-2023

million) depends on drinking water with a concentration of fluoride greater than the safe limit described by the WHO, which is 1.5 mg L-1. Fish and tea contain high fluoride content, and hence members of the population eating this food are more prone to fluoride exposure.

Consequently, studying the sustainability of excessive fluoride in groundwater and its hazardous impact on people is critical worldwide. Herein, we aim focus on the severity and seriousness of this issue by analyzing the current studies and presenting information on the exclusive and extraordinary Indian research on the effect of a higher natural concentration of fluoride in groundwater and the public scientifically. Furthermore, we aim to dissect the origins, bioavailability, and geochemistry of fluoride and its worldwide rank, focusing on human health consequences.

Fluorine: Chemical Profile

Fluorine (F2) is a halogen group member in the periodic table. It is a gas with a corrosive nature and has a characteristic pale, yellow-green colour. It has high reactivity and electro negativity. Fluoride is obtained as a reduced form of fluorine, which is a monovalent ion having a charge of -1, like other halides. It possesses distinct properties in compound form compared to other halides. It resembles hydroxide ions both structurally and chemically. Both the fluoride ion (F-) and bi-fluoride ion (HF2-) are obtained as a result of a solution of inorganic fluoride in water. Some inorganic fluorides without insignificant hydrolysis are water-soluble. Due to the smaller radius/charge ratio of fluoride, it has a high solvation effect, and also in comparison to chloride and other halides, fluoride appreciable dicers in terms of reactivity. Naked fluoride refers to fluoride ions that are almost relatively unsolved and behave as a solid Lewis base. For the detection of the fluoride and its compound fluorine-19, nuclear magnetic resonance (19F NMR) spectroscopy is used.

Sources of fluoride- Natural resources and manufactured-generated industrial pollutants are the primary sources of excessive fluoride in the environment. Fluoride is naturally added to ground and surface water by fluoride-rich natural rocks and soil that water interacts with them. Because of the deterioration or leaching of fluoride-bearing rocks during the percolation of water into the earth, groundwater becomes more contaminated than surface water, as shown in Fig. S1. The rate of evaporation, the length of time water spends in aquifer zones, and intense and long-term irrigation are all variables that influence how much fluoride is added to groundwater. The fluorine concentration in some mineral rocks is shown in Fig. S2. Fluorine (F2) is a greenish diatomic gas, which owing to its highly reactive nature, seldom occurs in its pure gaseous form except in a few industrial operations. The chemical, glass, and ceramic industries, coal power stations, semiconductor manufacturing units, electro- plating, brick and iron industries, aluminium smelting facilities, and beryllium extraction operations are some of the sectors that contribute the most fluoride-rich sequent. Fluoride is also introduced into the human body via everyday items such as toothpaste, mouthwash, medicines, cosmetics, and chewing gum.

Paths of fluoride uptake- Water, medicines, food, air, and cosmetics products are vulnerable sources of fluoride absorption. Water and other food sources are the most common sources of ingested fluoride. Fluoride is found in water as a fluoride ion and has a concentration of about 625 mg kg-1 in the crust of Earth. Fluorosis in humans is mainly induced by consuming fluoridated water. Fluoride may be found in various concentrations in all-natural water sources. The geological, chemical and physical properties of aquifers, soil and rock acidity and porosity, temperature of the corresponding areas, the depth of wells, and the impact of other chemicals influence the fluoride concentration in groundwater. The fluoride concentration present in drinking water is minimal, while in seawater, it is approximately 1.3 parts per million (ppm). The range of fluoride in the freshwater supply generally varies between 0.01–0.3 ppm, whereas in the ocean it is in the range of 1.2–1.5 ppm. The solubility of fluoride in water limits its concentration to 3.1 mg L-1 in the presence of calcium, which has a concentration of 40 ppm. If calcium is not present in the solution, then its higher concentration is also stable. Hence, the groundwater in regions having fluoride-bearing minerals and calcium-poor aquifers is expected to have a higher fluoride concentration.
The fluoride concentration is also expected to increase in groundwater where action exchange of sodium for calcium occurs. On the ground, fluoride-rich bands extend from Syria to Libya, Egypt, Jordan, and Kenya, and from Turkey to China, Northern Thailand, and India. The fluoride concentration in freshwater sources is shown in Fig. S3 (ppm in percent), and the fluoride concentration in minerals and soils (mg L-1 in percent)

Fluoride is found in almost all foods in tiny amounts. The amount of fluoride in food is determined by the soil, water, and fertilizers used for irrigation and agriculture. Compared to water and soil, the effect of fluoride entering the body via food and drinks is smaller. Various food items such as wheat, cabbage, tea, carrots, spinach, and some drinks contain fluoride, which enters the human body. The fluoride in these products is most likely due to the use of fluoridated water from the soil or fertilizer for food and beverage production. Tea plants absorb a high content of fluoride, with 97% of it accumulating

ISSN NO.-2347-2944 (Print)
e-ISSN NO.-2582-2454 (Online)
Vol.-16, No.- IV, Issues-30, YEAR- Oct.-Dec.-2023

in their leaves. Tea leaves have a fluoride concentration of about 97% that of the soluble fluoride in the soil, and it also has 2 to 7 times the full amount of fluoride in the soil. The fluoride content in regular strength instant tea in distilled water is 3.3 ppm, which causes dental fluorosis. Tibetan children exhibit dental fluorosis as a result of drinking brick tea, which has a high fluoride content of 493.2–1000 mg kg-1 compared to black tea (23.6–52.1 mg kg-1) and green tea (232–240 mg kg-1). The fluoride concentration in tea beverages from India, Tibet, and China range from 1.55–3.21 ppm, 2.59 1.73 ppm, and 1.60–7.34 ppm, respectively. Fig. S5(a) and (b) show the specifies of fluoride- rich foods.

Long-term usage of some medications, such as aspirin, has been linked to fluoride toxicity. Sodium fluoride is used to cure osteoporosis, niflumic acid is used to treat rheumatoid arthritis, and a fluoride-based mouth rinse is used to prevent cavities. Fluoride supplements containing inorganic fluoride in drinking water, pills, and other medications prevent tooth decay. The anti-inflammatory drug niflumic acid is used to treat rheumatoid arthritis. Sodium fluoride is a fluoride salt that is used in mouthwash to prevent cavities in the mouth.

Fluorides are extensively distributed in the atmosphere due to the industrial manufacture of phosphate fertilizers, manufacture of aluminium, coal ash from coal combustion, and volcanic activity. However, air exposure only accounts for a tiny portion of the overall fluoride exposure. In comparison to non-industrial regions, fluoride exposure in the air is higher in industrial zones. In parts of Morocco and China, there is a large amount of fluoride in the air. In particular Chinese regions, the indoor burning of high-fluoride coal for cooking produces 16 to 46 g cm-3 of fluorides in the air. Fluorosis affects ten million individuals in China due to the burning of high-fluoride coal.

Fluorides are present in daily use goods such as mouthwash, toothpaste, and cosmetics. Raw materials such as calcium carbonate, talc, and chalk are used for manufacturing these goods, increasing the fluoride levels between 800 and 1000 ppm. In fluorinated brands, fluoride is added in the range of 1000 to 4000 ppm. Various products that contain fluorides are employed to minimize dental decay in children. They include toothpaste with 1.0 to 1.5 g kg-1 fluoride, fluoride solution, and fluoride gels, corresponding to the topical treatment between 0.25 and 24.0 g kg-1 of fluoride, and fluoride tablets with around 0.25, 0.50, and 1.0 mg fluoride per tablet, which are responsible for direct fluoride contact in the children. It was estimated that toothpaste swallowed by a few children had nearly 0.50 or 0.75 mg of fluoride per day in one child.

The fluoride levels in soil typically range from 200 to 300 parts per million. Fluoride is not easily leached from soils because it is held in the soil via solid through interactions with the various components present in the soil. The amount of fluoride in the soil increases with the depth, with just 5% to 10% of the complete fluoride inside soil being water soluble. The chemical form, deposition rate, soil chemistry, and temperature influence the destiny of inorganic fluorides discharged into the soil, where most fluorides in acidic soils with pH < 6 are present in complexes related to aluminium or iron or on the displacement of hydroxide with the surface of the clay, fluoride bonds to it. The pH and fluoride concentration have a significant impact on the adsorption of fluoride, which is most noticeable between pH 3 and 4 and diminishes at pH 6.5. The presence of Cl-, SO24-, F- and NO3- in groundwater is caused by fertilizer application under heavy irrigation.

Groundwater from irrigated fields and soils has a higher fluoride concentration owing to alkalinization. According to the research by Watanabe et al., fluoride and hydrofluoric acid are absorbed via the skin in human beings and animals. Fluoride is absorbed and quickly transported throughout the body through blood, with approximately 99% of it ending up in bones and teeth.

Fluoride is absorbed from the stomach through an inert diffusion procedure, which is inversely proportional to pH, but quickly absorbed from the small intestine following gastric emptying. Fluoride absorption is reduced with the availability of a calcium-rich diet and contact with CaCO3. In soul tissues, there is no fluoride accumulation, although hydrogen fluoride may penetrate the intracellular fluid of soul tissues. The fluoride concentration in soul tissues reflects the fluoride concentration in the blood. It is highly concentrated in the renal tubules, at a concentration higher than that in plasma. Due to its higher contact with fluoride, the kidney may be a possible location and target of chronic fluoride damage. The placenta may regulate fluoride transfer from maternal blood to fetal blood in humans, while fluoride is only weakly transferred from plasma to milk. Human milk has been shown to have fluoride levels between 5 and 10 g L-1. Saliva excretes around 1% of ingested fluoride or less, where the saliva fluoride concentrations seem to reflect the plasma fluoride levels. Low amounts of fluoride were found in sweat, according to Henschler et al., which were around 20% that of the plasma levels. Fluoride excretion by the kidneys accounts for 35% to 70% of the fluoride consumed in adults. Consequently, indicators of acute fluoride exposure may be seen in the urine, plasma, and saliva. The fluoride concentrations in drinking water and the level of fluoride in the clippings of a fingernail are directly related, as shown by studies in Hungarian and Brazilian children, which suggested that

ISSN NO.-2347-2944 (Print)
e-ISSN NO.-2582-2454 (Online)
Vol.-16, No.- IV, Issues-30, YEAR- Oct.-Dec.-2023

the levels of fluoride in the fingernails are a reliable biomarker of direct contact with it, and thus they are not well consistent for plasma or bone.

However, the level of fluoride in the nails reflects its consumption three to six months before.55 Adults living in regions with 1.0 mg L-1 fluoride in the water have an average dietary intake of 0.02–0.048 mg per kg per day, whereas those living in places with less than 0.3 ppm fluoride in the water have an average dietary intake between 0.004 and 0.014 mg per kg per day. In regions with fluoridated water, that from food consumption by children varies from 0.03 to 0.06 mg per kg per day, whereas in areas without fluoridated water, it is 0.01 to 0.04 mg per kg per day.56 Infants bottle-fed with fluoride water reconstituted milk formula consume between 0.12 and 0.18 mg per kg per day. The total fluoride intake for babies with an average weight of 8.1 kg at six months is between 1.0 and 1.5 mg per day, which is an adult dose. In humans, Li et al.58 proposed the lowest observed-adverse-effect level (LOAEL) of 0.25 mg fluoride per kg per day and no-observed-adverse-effect limit (NOAEL) of 0.15 mg fluoride per kg per day, but these values are presently under dispute.

The sources of fluoride in the environment include industrial plants, aluminium smelters producing glass brick, hydrofluoric acid, tile works and phosphate fertilizer plastic factories, textile dyeing, and industries that consume high sulphur non-coking coal for thermal power. Currently, high-tech companies developing semiconductors and integrated circuits produce significant fluoride-containing industrial wastewater. Cigarettes, which contain an average of 236 ppm fluoride, play a significant role in human fluoride consumption.60 Teflon-coated cookware may potentially increase the fluoride absorption in humans. The fluoride concentrations in Teflon-coated cookware is as high as almost 3 ppm, whereas it is lower in aluminium cookware. Also, the fluoride concentrations are high in stainless steel and Pyrex ware, although to a lower extent. In normal and high quantities, fluoride in water may cause aluminium to leach from cooking utensils and copper from pipe work.

Contamination in ground water- The contamination of groundwater with fluoride is now one of the most significant global issues, given that this contamination is natural and inevitable. Fluorosis is an endemic disease in tropical climates but only to a certain extent. A high fluoride concentration in water in extensive geographical belts is associated with (1) volcanic rocks, (2) marine origin sediments in mountainous regions, and (3) granitic and gneissic rocks. This contamination occurs due to two main factors, which are re- ported to be geogenic and anthropogenic sources.

Geogenic source- Fluoride is present in various rocks in the Earth's crust, posing an average value of 625 mg kg-1. The increase in the fluoride content in groundwater is attributed to several geological processes. Geothermal springs, volcanic activities, tectonic processes, weathering, and other geological processes involving rock and water contact are the main routes for fluoride contamination. The fluoride concentration in water is positively associated with ions such as chloride and phosphate, whereas that with the calcium ion is negative. The generation of water with the loss of water from the system via evaporation has been studied using isotopic data such as carbon (C), oxygen (O), and hydrogen (H) isotopes. Also, it was determined how various aquifers are connected and how climate influences fluoride concentration. After much research, it has been found that the geogenic sources of fluoride contamination are the main reason for population exposure due to the intake of groundwater polluted with fluoride. Several minerals such as fluorite, topaz, and their parent rocks including granite, basalt, and shale release fluoride in the groundwater. The mobilization of fluoride through the leaching of rocks and over-utilization of groundwater is the root cause of fluoride contamination. Fig. S6 depicts the different rocks and their fluoride content (mg kg-1). Soil and rocks are natural sources of fluoride. Moreover, natural leaching, which occurs during the percolation of water through the soil and rocks, plays an essential role in groundwater contamination. There are also some indirect ways by which groundwater contamination occurs, including storage of water between soil and rocks for a long time, evaporation of water, and use of irrigation systems for an extended period. The fluoride ion can occupy the hydroxide ion site by replacing it in the mineral structure given that these two ions are negatively charged and are almost similar in size. The modification of rock minerals and discharge of the dissolved compound occur via geochemical processes due to the exposure of rocks to weather agents such as water. The dissolution of minerals containing fluoride in rocks is accelerated by temperature and residence time. When the alkalinity of groundwater is high, hydroxyl ions quickly replace the fluoride ions in minerals such as mica, elite, and amphiboles. Moreover, many bicarbonate and sodium minerals enhance the concentration of fluoride in the groundwater. The possibility of fluoride dissolution increases when calcium-rich groundwater changes to sodium-rich groundwater.

Health effects- Fluoride may be helpful or harmful for humans depending on the overall concentration of fluoride consumed over a period. A deficiency in fluoride causes dental caries and weakening of the bones when its concentration is less than 0.5 mg L-1, whereas if there is an intake of more than 1.5 mg L-1, it causes fluorosis. The accumulation of fluoride more than the permissible limit leads to hazardous health issues in infants, children, and adults. The deferent effects of fluoride on the human body are shown in Fig. 1. Fluoride will not affect a person briefly, but it gets stored in the brain and slowly deteriorates the body with time, as shown in Fig. 2.

The primary basis of fresh water is groundwater, which is the most consumed form for irrigation purposes. According to the report presented by the WHO, more than 25 countries have a concentration of fluoride more than the permissible limit, and nearly 200 million people depend on the contaminated water, which is a severe threat causing health issues to consumers. Many African countries have a higher fluoride concentration than the guideline set by the WHO of 1.5 mg L-1. The

Asian countries with a high fluoride concentration in their ground- water include Bangladesh, China, India, Indonesia, Iran, Iraq, Jordan, Korea, Pakistan, Palestine, Saudi Arabia, Sri Lanka, Syria, Thailand, Turkey, and Yemen. The regions of Canada, Mexico, and the United States especially need defluoridation due to the high fluoride concentration in their groundwater. Even countries of Latin America, namely Argentina, Ecuador and Peru, have high fluoride concentrations in their ground- water. A excessive concentration of fluoride in groundwater is a significant problem in European countries. Some regions of Germany also face this problem.

In 1937, the Prakasam area of Andhra Pradesh reported the first incidence of fluorosis endemic in humans. Only four states of India, namely Andhra Pradesh, Uttar Pradesh, Punjab, and Tamil Nadu, were recognized with fluorosis patients in 1950. Currently, fluoride is present in 20 of India's 29 states, which is projected to rise, as shown in Fig. 4. Fig. 4 displays a map of India with fluoride in the drinking water in all districts.95 In India, just a few families with fluorosis were found in 1937. However, fluorosis was projected to affect 25 million individuals in India by the United Nations International Children's Emergency Fund (UNICEF) in 1995. Currently, fluorosis affects 66 million people in India, with 6 million children less than 14. Around 411 million individuals in 201 districts across 20 states are affected by fluoride in India, and thus are possibly in danger of fluoride poisoning.

Dental- Dental caries is the world's most common issue in children. Fluoride plays a significant role in minimizing the chance of enamel fluorosis and preventing dental caries. During the developmental period of teeth, continuous exposure to fluoride helps develop resistance against dental decay and fluorosis of the enamel. The enamel is the most mineralized hydroxyapatite crystal, which is rich in carbonate, but deficient in calcium. To maintain the state of stable equilibrium with the fluid in the surrounding region of the crystal, a sufficient amount of ions such as Ca2+, PO43-, OH-, and F- are present. During cariogenic acid attack, the pH value in the vicinity of the tooth decreases due to the release of H+ ions from organic acids, which are formed by plaque bacteria from carbohydrates. These H+ ions are released to interact with the phosphate ions (PO43-) available in plaque fluid and reduces them to HPO42-, and finally H2PO4-. This reduction process helps to release calcium from potent tooth substances and also balances the neutrality. Compared to the incorporated fluoride, the smaller quantity of fluoride present in the solution in the vicinity of the tooth more effectively prevents the process of demineralization. Moreover, it also can inhibit dental caries more than the large amount of fluoro-hydroxyapatite in the enamel. This protection is ascribed to the fact that the fluoride ions present in solution are more effective to prevent caries than the fluorides present in the enamel crystals. Now, a small amount of fluoride ions is adsorbed on the crystalline surface, and a state of dynamic equilibrium is achieved between the fluoride ions in solution in the vicinity region and the adsorbed fluoride ions. Finally, this adsorption inhibits the process of demineralization. The presence of fluoride in the correct amount ($0.7 mg L-1) is significant for developing dental enamel and normal mineralization of bones. Up to 40% of tooth decay can be prevented by fluoride.

Teeth and bones- An essential constituent of the tooth enamel and skeleton is hydroxyapatite. The hydroxide ions replaced by fluoride form a significantly harder compound called fluorapatite. If present in a small amount, fluorapatite prevents the tooth from decaying and reinforces the tooth's enamel. However, if fluoride at elevated doses is taken for a long time, then the hydroxyapatites get converted to fluorapatite in a more significant amount, making the bone and teeth stiffer and brittle and promoting the disease called dental fluorosis. Dental fluorosis gets converted to skeletal fluorosis as the fluoride concentration increases to 3.0 mg L-1. About 65% of the endemic fluorosis, which occurs due to fluoride-contaminated drinking water, is reported in arid and semi-arid regions. Table S2† shows the effect of prolonged use of drinking water on human health, which is related to its fluoride content.

Crippling skeletal- fluorosis is considered one of the leading causes of morbidity in a large area of the globe. If the fluoride present in drinking water is less than 0.5 mg L-1, then the possibility of dental caries increases in children. If the amount of fluoride present is up to 1.5 mg L-1, it helps strengthen the skeleton. The threat of skeletal and dental fluorosis increases with an increase in the fluoride concentration in water. The most common problem encountered is the mottling of the teeth when the fluoride concentration is in the range of 1.5 to 4.0 mg L-1. When the fluoride intake crosses 6.0 mg L-1, it opens the path for multidimensional health effects, mainly dental and skeletal fluorosis. Drinking water containing excess fluoride is responsible for almost 65% of the total endemic fluorosis. Out of the total fluoride consumed by the body, its maximum amount is retained by the bones or teeth, with almost 80–90% in new-born babies and 60% in adults, and the remaining fluoride gets excreted via the urine. The early symptom of dental fluorosis is enamel discoloration, which may convert to discrete or aggregated pitting.

Neural- When present in a concentration of more than 1 mg L-1, fluoride increases the chance of neurotoxicity, which may disturb the learning and memorizing capacity. Compared to the mature brain, the developing brain is more prone to damage by toxicants, which may lead to permanent damage. Current research has established that the mental ability of children in high fluoride areas is relatively lower than those living in low fluoride areas. A comparative study was carried out between 1988 and 2008 in China to relate the intelligence quotient (IQ) level with fluoride concentration and it was found that the children living in fluoride-enriched areas have a chance of low IQ by at least +ve times more than the children from the region having a lower fluoride concentration. The excess fluoride concentration increases the lipid peroxidation level and hinders various chief neuronal enzymes.

This study suggested that fluoride directly affects neurons, myelin, and neurotransmitters, suggesting that fluoride may directly damage the functioning of the brain. A characteristic study was performed to understand the correlation between neonatal neurodevelopment and fluoride intake by mothers during pregnancy. It was found that the neonatal neurodevelopment of babies was very slow when the fluoride intake by their mothers was large during pregnancy compared to the babies not exposed to an elevated fluoride concentration. After chronic fluoride administration, various changes occur in the blood, brain, and liver of animals, including metabolic lesions, abnormal behaviour designs, and changed neuronal cerebrovascular integrity. When the groundwater contains fluoride of more than 10 mg L-1, it accelerates more diseases such as neurological problems, hypertension, and cancer, which become challenging for human health.

Conclusion- Fluoride-contaminated water is a severe concern affecting human health, requiring highly effective environmental protection and water management. Given that anthropogenic factors release fluoride in the environment, it is a severe health issue, and most of the problems result from ingesting fluoride from natural resources. The guide of the UNSDG for clean drinking water shows a cost-effective, efficient, viable method to remove fluoride and is mandatory. This method avoids the fundamental drawbacks. It is noticed that it is hard to provide precise and substantial criteria due to a lack of adequate data.

Few researchers cannot focus on developing specified methods given that they combine various techniques to create synergistic methods for removing fluoride. This is responsible for bringing about growth and development in water engineering by employing the present and suitable methods, surpassing most minor efforts for practical use. Together with the literature, the narrative of this study is limited to fluoride removal method from aqueous solution, which cannot transcend the investigation on its recovery and re-use, and disposal of secondary polluting agents. Local communities should be notified and informed to assist in developing appropriate and low-cost curative technologies.

Defluoridation of water and minimizing fluoride consumption are also necessary for the integrated mitigation of fluorosis. There is a need to raise awareness in fluorosis-prone regions about the need to eat foods with a low fluoride content and avoid meals with high fluoride concentrations. It is recognized that a comprehensive approach to fluorosis mitigation is necessary and that an appropriate strategy for water defluor- idation, fluoride consumption reduction via foodstuffs and consumable products, and nutritional supplementation may be required. Due to the lack of communication, initiatives and public awareness, combatting fluorosis on a large scale has remained a dream. Mass media and social media may aid in fluorosis prevention and control. A comprehensive strategy is required to address the threat posed by fluoride. However, the principle of "prevention is better than treatment" remains the ultimate answer to the fluoride problem. Furthermore, narratives from the reviewed literature are restricted in their assessment of possible fluoride recovery, re-use, and/or disposal of secondary pollutants created. Consequently, we advise future researchers to take a more thoughtful and comprehensive approach to future studies. Finally, by using a comprehensive approach to examine the complex challenges of F- pollution, our study indisputably proves the importance of diverse exposure path- ways and human health hazards. Therefore, it is suggested to the upcoming researchers that they should have a more conscientious and holistic method to investigate the fluoride concentration.

ISSN NO.-2347-2944 (Print)
e-ISSN NO.-2582-2454 (Online)
Vol.-16, No.- IV, Issues-30, YEAR- Oct.-Dec.-2023

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