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A Theoretical Assessment of Seasonal Variations in Fluoride Contamination and Its Implications for Dental Health

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ABSTRACT

Groundwater contains naturally occurring fluoride, which has a dual purpose in human health: while small amounts protect teeth from cavities and improve enamel, consuming too much of it can cause serious health problems like skeletal and dental fluorosis. Groundwater fluoride poisoning, seasonal changes, and their effects on oral health are all covered extensively in this article. Children exposed to high quantities of fluoride (>1.5 mg/L) may experience neurodevelopmental impacts, tooth discolouration, pitting, skeletal abnormalities, and, in the worst-case scenario, decreased bone mineral density. Children are particularly at risk for dental fluorosis, according to epidemiological data from Kenya, Mexico, India, and China, where excessive groundwater fluoride levels are associated with a high prevalence of the disease. It is crucial to continuously monitor groundwater fluoride levels rather than relying on measurements taken during a single season since the risk of exposure is greatly affected by seasonal changes in fluoride levels, which occur before the monsoon, during the monsoon, and after the monsoon. The study goes on to say that fluoride levels and the health concerns they pose are affected by a variety of geological, environmental, and socioeconomic variables. To decrease fluoride exposure and avoid long-term health effects, mitigation measures are necessary. These include defluoridation, the provision of clean drinking water, public education, and nutritional treatments. In order to develop targeted interventions in areas where fluoride pollution is prevalent, conduct accurate risk assessments, and influence public health policy, it is essential to understand the geographical and temporal variability of fluoride contamination.

Keywords: Fluoride Contamination, Groundwater, Dental Fluorosis, Skeletal Fluorosis, Seasonal Variation, Public Health, Defluoridation.

I. INTRODUCTION

Fluoride (F⁻) is a naturally occurring element found in groundwater and various outside influences. Although little levels of fluoride are good for your teeth (they prevent cavities and strengthen enamel), consuming too much of it can be harmful. Communities that depend mostly on untreated groundwater for household and drinking uses have seen fluoride pollution of groundwater become a major public health hazard in recent decades.

One obvious effect of fluoride overexposure is dental fluorosis, which develops when teeth are exposed to high quantities of the mineral from birth until about the age of eight. The hypo-mineralization of the enamel, which can range from small white streaks to large brown stains, pitting, and structural



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deterioration, are the hallmarks of this condition. Dental fluorosis develops when ameloblast function is disrupted during amelogenesis, resulting in the formation of porous and fragile enamel. Once this enamel has taken place, it cannot be repaired. Individual sensitivity, dietary condition, renal function, and the amount, timing, and duration of fluoride exposure all have a role in how severe dental fluorosis can be.

Dental fluorosis prevalence is strongly correlated with groundwater fluoride concentrations, according to epidemiological studies. Dental fluorosis affects a disproportionately large number of youngsters in India; in fact, it can impact as much as 80% of the population in regions where fluoride levels are higher than 1.5 mg/L. Countries like Mexico, Kenya, and China have also seen similar trends, especially in areas where groundwater is used for drinking water. Because low-income areas typically do not have access to purified water and are less informed about the dangers of fluoride, environmental and socioeconomic factors also play a role in modulating this association.

Fluoride exposure has far-reaching consequences on public health. In addition to aesthetic issues, severe dental fluorosis can cause functional problems, sensitivity to food and drink, infections of the mouth and gums, and psychological and social consequences like shame and low self-esteem. Skeletal fluorosis, which impacts the health of bones and joints, can be a result of extremely high fluoride exposure. Some ways to lessen the impact of these dangers include defluoridation, making water safe to drink, dietary changes, public awareness campaigns, and early dental screenings.

Variations in fluoride pollution throughout the year and their effects on oral health are theoretically evaluated in this paper. It compiles data from prior research on the distribution of fluoride in groundwater, the prevalence of dental fluorosis, and the environmental, geological, and socioeconomic variables that have been found to play a role. Researchers, public health workers, and lawmakers can craft more effective strategies to lower fluoride exposure and lessen its negative health impacts if they have a better grasp of these trends.

Contamination of Fluoride in Water

Fluoride is a necessary component of water for healthy teeth and bones, but human health is negatively impacted at quantities greater than 1.5 mg/l. Teeth mottling and skeletal fluorosis are side effects of drinking water with fluoride concentrations above 1.5 mg/l, which are harmful to human health. Additionally, it causes osteopenic and osteoporosis disorders by reducing bone mineral density. Infants' intelligence may suffer as a result of fluoride buildup in their brains. In addition to causing skeletal abnormalities and knock knees (genu valgum), increased fluoride consumption makes bones more brittle and less stable. In addition to causing osteo-dental fluorosis and other health issues in humans, fluorinated groundwater is harmful to a wide variety of domestic animal species. Groundwater fluoridation has been linked to the recent emergence of bioindicators of endemic fluorotoxicosis.



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Millions of individuals throughout the world are putting their health at danger because of the high levels of fluoride in their drinking water. Some nations that are particularly vulnerable to the effects of fluoride include Mexico, Argentina, China, and India. Groundwater contaminated with excessive amounts of fluoride affects millions of people in Mexico alone. Groundwater contaminated with fluoride affects a big portion of Argentina as well. The majority of the time, greater fluoride concentrations are explained by underlying geological processes. On the other hand, fluorosis is common in parts of western and central China, where people not only drink water contaminated with fluoride but also breathe in fluoride gas produced by burning coal. An uncommon source of fluoride for a large section of the population in certain locations has been brick tea consumption.

It was in 1937 in the Nellore area of Andhra Pradesh that the issue of elevated fluoride levels in drinking water in India was initially documented. The adjacent Nalgonda district was later found to be one of the most severely fluoride-contaminated places, prompting the development of the "Nalgonda Technique" to purge drinking water of fluoride. Fluorosis is common in a number of Indian states, according to thorough assessments, and excessive levels of fluoride in groundwater have a devastating effect on several districts. Groundwater containing high amounts of fluoride has been found in nearly every state in India. To date, fluorosis has been identified as one of the most pervasive environmental health concerns in India, affecting an estimated 66 million people (4 million of whom are children younger than 14). India has large fluoride reserves; therefore, the magnitude of the problem is not unexpected.

Governmental and non-governmental groups have responded to the health concerns raised by fluoride contamination. The study of millions of well samples taken across India determined whether areas or wells were contaminated with fluoride or not. Fluoride concentrations can vary with the seasons, but these samples generally failed to account for that. Fluoride levels can be impacted during certain seasons yet deemed safe during others, depending on seasonal oscillations such as the pre-monsoon, monsoon, and post-monsoon periods. Thus, in order to properly evaluate the groundwater safety for human consumption, monitoring programs should take seasonal fluctuations into consideration.

II. REVIEW OF RELATED STUDIES

Gaddam, Yasaswini et al., (2024) Concerns about fluoride (F^-) in groundwater and its possible health consequences on humans have grown in importance over the past few decades. Therefore, this study combined a regional-scale analysis of the frequency and trend of F^- distribution in groundwater [2014-2018] with field-based investigations carried out locally to assess the exposure of a small sample of families (10 households and 35 respondents) and the reasons behind their consumption of F^- containing water ($n = 18$). Researchers in the area collected water samples from a variety of sources close to the selected residences; they then classified the samples as either drinkable or non-drinking. Andhra Pradesh's groundwater contains F^- levels that are too high, and they've been going up steadily (with a standard deviation of 0.55) since 2014. The average concentration of fluoride in groundwater was 1.5



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mg/L, according to a local research, while the concentration in other water sources was less than 1 mg/L. While nine homes are using water from public sources that does not contain cyanide (<0.52 mg F⁻/day), one household is exposed to over three milligrams of cyanide daily through drinking groundwater. This disparity in fluoride exposure is determined by policies about health exposure and economic stability.

Mandal, Juthika et al., (2023) the vast majority of the purely district's population—90% to be exact—hoils from rural areas and gets most of their potable water from underground sources. However, the groundwater in all 20 blocks of this district is heavily contaminated with fluoride. Here, we assess the distribution pattern of fluoride using Moran's Index and hotspot analysis applied to fluoride contamination data collected in 2019 and 2020. Both long-term and short-term issues can be better addressed with the help of this research.

Mansur, Eman. (2023) of all the non-metals, fluorine is both the most electronegative and the most reactive. Forming fluorides with all elements except oxygen and noble gases, the element is rarely seen in nature in its elemental state. People can obtain fluoride (F), a mineral, through the air, water, and food they eat. The processes mentioned earlier are all part of F metabolism, which also includes excretion. Topical administration of F is distinct from systemic absorption of F. Because F can have systemic and topical effects by any route of administration, these distinctions are meaningless (Murray and Naylor 1996). F has been a major factor in the decrease of dental caries prevalence since its anti-caries effect was found in 1938 by Dr. Trendly Dean. Over time, at safe doses, F has no physiological effect on humans. Like any substance, there is an optimal amount of F ingestion; however, there are limitations beyond which the effects become harmful. Fluorosis of the skeleton and teeth, along with other symptoms like gastrointestinal, neurological, and urinary problems, can be caused by exposure to F at high enough levels. These adverse effects might be characterized as either acute or chronic toxicity.

Kumari, Priyanka & Misra, Anil. (2023) Groundwater containing high levels of fluoride can have disastrous consequences on the health of humans, especially children. Researchers set out to quantify the possible dangers to children's health from increasing fluoride intake in drinking water among those in the age bracket of 5 to 15. There were 195 groundwater samples that were examined for various water properties. By analyzing unique data on water quality, the non-carcinogenic health risks of children's high fluoride consumption were evaluated. The findings showed that Monger contains fluoride in concentrations ranging from 0.029 to 12 (mg/l), with 13.8% of the samples having concentrations higher than the allowed limit of 1.5 mg/l. The hazard quotient value for skin exposure is between 0.001 and 0.012, whereas the value for drinking water with high fluoride levels is between 0.625 and 8.571. Consequently, in Monger, the total hazard quotient varied between 0.626 and 8.58. From what we can see, the water supply in Monger exposes youngsters to high levels of fluoride, putting them at high risk of non-carcinogenic health issues. The results of the sensitivity analysis indicate that fluoride concentration is the primary factor influencing the non-carcinogenic health risk.



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Goutam, Chanchal et al., (2022) Groundwater contamination with fluoride (F⁻) is just as bad for people and plants. A fluoride concentration of 0.6 mg/l or greater is required for human consumption water if it is to strengthen teeth and bones. Fluoride toxicity has been a source of concern in more than 25 countries. The present study aims to evaluate the physical and chemical properties of groundwater. The water samples were collected from rural areas of Meerut city. Specific chemical and physical constraints, including concentrations of fluoride, total dissolved solids, electrical conductivity, salinity, turbidity, including pH All of the groundwater sites tested showed fluoride quantities more than 1 mg/l, according to our investigation into water pollution levels. Because of this, using groundwater for irrigation or human use is not a good idea. Numerous differences were identified in the present investigation.

III. IMPACT OF EXCESSIVE FLUORIDE ON ENAMEL DEVELOPMENT AND ORAL HEALTH

Dental fluorosis can occur if the teeth are exposed to too much fluoride during their formative years, which typically begin at birth and last until the child is eight years old. This can interfere with the growth of the tooth enamel. Symptoms of this illness include enamel pitting, surface irregularities, and hypo mineralization of the enamel, which shows both structurally and cosmetically in teeth as anything from tiny, nearly imperceptible white spots to bigger, more noticeable brown stains. The condition is linked to fluoride exposure while enamel is still developing and cannot be reversed. Instead of dental caries, which occurs when tooth enamel is eroded by bacterial acids, dental fluorosis is caused by systemic fluoride poisoning, which impacts normal enamel production before teeth erupt. Ameloblasts produce enamel during melogenesis, the first step in the pathogenesis of dental fluorosis. Ameloblasts begin mineral deposition and form a protein matrix that is the enamel during the first secretory stage of amelogenesis. Excessive fluoride induces proteolytic enzyme function impairment, which in turn promotes oxidative stress in ameloblasts and hinders protein synthesis and secretion. Consequently, the protein components of the enamel matrix are preserved throughout mineralization, which is an excellent finding. The result is adult enamel that is less calcified and more porous, and the degree to which this changes is directly correlated to the amount and duration of fluoride exposure.

One factor that influences the degree of dental fluorosis is the total quantity of fluoride taken in when teeth are growing. Many factors come into play, including the duration and severity of exposure, one's nutritional status, renal function, and susceptibility. Dental fluorosis typically manifests during the formative years of a person's teeth, when their permanent crowns are still being formed. Excessive fluoride use during this susceptible phase significantly raises the risk of fluorosis. Fluoride can be consumed in a variety of forms, including water, toothpaste, food, supplements, and even foods prepared with fluoride-rich water. The cumulative impact of many fluoride sources is a common cause of dental fluorosis in regions with naturally high concentrations of fluoride in groundwater.



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The rate of dental fluorosis is affected by environmental, social, and geographical factors. Worldwide, nations with naturally occurring groundwater fluoride concentrations above 1.5 mg/L have a higher incidence of dental fluorosis. Parts of the US, Mexico, Ethiopia, India, and China are all part of this. So are parts of Kenya. Fluorosis can be seen in locations where the content of fluoride in drinking water is moderately elevated, ranging from 2 mg/L to above 10 mg/L. Consider the approximately 60 million people in various Indian states who have dental and skeletal fluorosis; this condition is mostly caused by the long-term consumption of fluoride-contaminated groundwater. Especially bad is the situation in states like Rajasthan, Andhra Pradesh, Gujarat, and Uttar Pradesh where fluoride levels are high and where people do not have easy access to safe drinking water.

Dental fluorosis is very widespread, according to surveys of school-aged children in many affected areas. Studies have shown that in areas where the drinking water contains fluoride concentrations of 2-4 mg/L, over 40-60% of children may show signs of dental fluorosis. Fluoride levels exceeding 4 mg/L impact almost 80% of the population in specific locations, and the problem gets much worse and more common when those levels rise. The Thylstrup-Fejerskov Index and Dean's Index are two examples of evaluation indices that categorize the degree of fluorosis based on the extent of enamel changes. According to Dean's Index, there are six different degrees of dental fluorosis: normal, questionable, very mild, mild, moderate, and severe. Under mild conditions, the visible white opaque areas will not cover more than 25% of the tooth surface. White patches grow increasingly apparent and may even cover the entire tooth in cases of severe disease. Severe fluorosis manifests as brown discoloration, erosion of the enamel, and dental defects as putting and chipping.

Although mild cases of dental fluorosis are often only noticed for their aesthetic value, more severe cases can lead to significant functional, social, and psychological issues. Adolescents and young adults who suffer from visible tooth discolorations or malformations may experience low self-esteem, social humiliation, and stigmatization. In places where fluorosis is not widely recognized, people who suffer from it may unjustly be considered to have other health problems or to have poor oral hygiene. In cultures where obvious dental issues are seen as a hindrance to marriage and professional success, women experience a disproportionate amount of the social stigmatization linked with this condition. The detrimental impact of dental fluorosis on public health is exacerbated by its psychological and social consequences, which are especially noticeable in communities with inadequate resources. In addition to the apparent aesthetic concerns, severe dental fluorosis can amplify tooth sensitivity, obstruct cleaning, and increase susceptibility to mechanical wear and fractures. Even though fluorosis enamel is usually better at withstanding acid attacks and dental caries, you should be aware that the tooth's uneven and porous surface can hold onto bacteria and food debris. It is essential to maintain basic hygiene to avoid gingival problems and mouth infections. Additionally, a high fluoride exposure level is associated with severe dental fluorosis, which can progress to skeletal fluorosis—a far more dangerous condition that can damage bones and joints.



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Reducing the frequency and severity of dental fluorosis requires an integrated public health strategy. Reducing fluoride exposure is the primary strategy, particularly during the tooth-forming years. In places where groundwater naturally contains significant concentrations of fluoride, this could involve collecting rainfall, switching to surface water, or implementing defluoridation techniques at the home or community level. The Nalgonda procedure, reverse osmosis, and activated alumina filtration are three popular methods for defluoridation. Water treatment projects should be accompanied with public awareness programs that teach people about the risks of fluoride exposure, why children should use fluoride-free toothpaste, and why it's important not to mix infant formula with water that's high in fluoride.

Additionally, nutritional therapy may help reduce fluorosis to a certain degree. Consuming an abundance of foods rich in antioxidants, vitamin C, and calcium can help mitigate the effects of fluoride on developing bones and teeth. In areas where fluoride is abundant, school lunch programs and community health initiatives can increase children's dietary intake, which can help reduce the risk of fluoride poisoning.

IV. CORRELATION BETWEEN GROUNDWATER FLUORIDE AND DENTAL FLUOROSIS

Tooth enamel is strengthened and protected from dental caries by trace amounts of fluoride, an element found in the Earth's crust. The other side is that it might be bad for your teeth if you drink too much of it, particularly in water. Among the many health issues associated with prolonged exposure to water that is rich in fluoride is dental fluorosis. The characteristic of this disease, which primarily affects children when their teeth are still forming, is darkening, staining, or pitting of the enamel. The high levels of fluoride in groundwater pose a serious threat to public health in many regions of the world, especially in rural and arid regions where surface water is not readily available. Knowing how groundwater fluoride levels relate to dental fluorosis prevalence and severity is crucial for developing effective mitigation strategies and protecting the public's health.

Geological and Hydrogeological Influence on Fluoride Levels

Local geological and hydrogeological factors influence the quantities of fluoride in groundwater. Mica, apatite, and fluorite are just a few of the minerals and rocks that contain fluoride. Weathering and leaching of these fluoride-bearing minerals into the groundwater in mineral-rich regions may improve the water's fluoride content naturally. Further factors that influence the release of fluoride ions include the amount of time that an aquifer stays underground, the temperature and pH of the water, the concentrations of bicarbonate and calcium ions, and the interchange of ions between rock and water. Fluoride, for instance, is more likely to remain dissolved in water in areas with low calcium content and alkaline conditions than to precipitate out. People whose water supply comes from these aquifers may be exposed to levels of fluoride that are too high for human health.



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Fluoride Absorption and Dental Enamel Development

The majority of the beneficial effects of groundwater fluoride on teeth and gums are often observed in children under the age of eight. At this stage, the development of the permanent teeth begins beneath the gums. Water with fluoride concentrations above 1.5 mg/L, the upper level recommended by the World Health Organization, interferes with the natural mineralization of enamel, which is harmful for children. Because of this, dental fluorosis occurs. The severity of fluorosis is determined by the duration, amount, and timing of exposure to fluoride. At high concentrations, it can cause brown stains, erosion of the enamel, and structural damage; at low to moderate concentrations, it can cause faint white spots or streaks. Keep in mind that there is no way to reverse dental fluorosis once it has begun.

Epidemiological Evidence Linking Fluoride and Fluorosis

Dental fluorosis rates are substantially and continuously connected with water fluoride levels, according to a considerable body of epidemiological data. Research in countries where groundwater fluoride levels are naturally higher than the allowed limit has shown an alarmingly high incidence of fluorosis in children. These countries include China, Mexico, Kenya, and India. For example, dental or skeletal fluorosis symptoms have been reported in millions of people throughout 200 districts in 20 states of India. Research in regions where the quantity of fluoride in the groundwater is greater than 2 mg/L suggests that a significant number of school-aged children may have dental fluorosis, the severity of which can vary. There is a statistically and clinically substantial correlation between entire communities exhibiting enamel discolorations and mottling.

Severity Grading and Fluoride Concentration

The Dean's Index is a widely used classification system that may be used to easily analyze dental fluorosis in relation to fluoride exposure. Classification of dental fluorosis from "normal" to "very severe" is based on the extent and kind of enamel weakness. The quantity of fluoride in the groundwater has a direct correlation to the severity of fluorosis.

When fluoride levels are between 0.7 and 1.2 mg/L, for instance, people's teeth are most protected and the risk of fluorosis is minimal; nevertheless, when levels are between 2 and 4 mg/L, moderate to severe fluorosis is prevalent. At doses exceeding 4 mg/L, the disease typically manifests as discoloration ranging from brown to black, pitting of the enamel, and surface tooth degeneration. There is more proof from this gradient that fluoride concentration directly correlates to the severity of dental fluorosis.

Environmental and Socioeconomic Factors Influencing the Correlation

While factors such as water fluoride content are the primary driver of fluorosis, environmental and socioeconomic factors may influence the severity of the disease. Consider the role of nutritional status, for example. Deficiencies in calcium and vitamin D increase the risk of fluorosis because these nutrients regulate fluoride absorption and bone health. To a similar extent, people in hot, dry climates



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are more likely to drink water containing fluoride, which leaves them more susceptible to the flu's effects. Furthermore, socioeconomic status affects the risk. Less affluent communities sometimes rely only on untreated groundwater because they lack the means to access other water sources, build water treatment facilities, or educate themselves about the dangers of fluoride.

Case Studies Demonstrating the Correlation

Numerous case studies performed across the globe have found conclusive evidence linking dental fluorosis to groundwater fluoride. Samples of water from the Anantapur region in the Indian state of Andhra Pradesh revealed fluoride concentrations as high as 10 mg/L. Research in this field of dentistry has revealed that over 90% of children exhibit signs of dental fluorosis, which can range from little white patches to noticeable brown discoloration and degradation of enamel. Because of the high levels of fluoride in the groundwater there from natural geothermal activity, endemic fluorosis has become a major health problem in the Rift Valley region of Kenya. Additional evidence of the association is the high occurrence of dental fluorosis in these places, which is closely associated with the long-term use of groundwater that is contaminated with fluoride.

Public Health Implications

A major public health concern is the strong correlation between dental fluorosis and groundwater contaminated with fluoride. Despite the lack of discomfort associated with dental fluorosis, it can have serious emotional and social consequences, particularly for younger generations. Tooth injury or discoloration can lead to feelings of embarrassment, bullying, and self-consciousness. In severe cases, people may also develop hypersensitivity and have difficulty keeping their lips clean. Fluorosis of the teeth can develop into skeletal fluorosis, a more serious and long-lasting disorder, due to greater systemic fluoride exposure. Hence, the moment a community reports dental fluorosis, it is imperative to examine water quality and total fluoride exposure.

Strategies for Breaking the Link Between Fluoride and Fluorosis

The link between dental fluorosis and groundwater fluoride needs immediate and coordinated intervention to dismantle. The most effective strategy is to provide access to safe drinking water. Part of this approach can involve finding aquifers with low fluoride concentrations or finding other water sources such piped treated water or collecting rainfall. It is important for communities to be informed about the risks of fluoride and to take steps to reduce their absorption of the mineral through dietary changes. This can be done through public health campaigns. Regular monitoring of groundwater fluoride levels and early dental screening in children may prevent severe cases and drive policy decisions.

V. SEASONAL VARIATIONS IN FLUORIDE CONTAMINATION

The amount of fluoride in groundwater varies greatly from one season to the next, and variations in the weather have a major impact on this. Hydrogeochemical processes in the subsurface environment,



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water table changes, recharge of aquifers, and precipitation all have a role in the seasonal variation. There are times of year when fluoride levels in drinking water can be too high, making these fluctuations vital for determining the risk of skeletal and dental fluorosis.

Pre-Monsoon Season

Groundwater levels are usually lowest in the months leading up to the monsoons because of the extended dry spells. Dissolved minerals, such as fluoride, are more concentrated in the remaining water when water levels are reduced. Fluorite, mica, and apatite are minerals high in fluoride, and when they weather and leach into aquifers, they release this mineral into the groundwater. Fluoride concentrations tend to be higher in the spring because of the reduced water volume and limited recharge during this time. During this season, populations that depend on open wells and shallow hand pumps for drinking water and household use are at a higher risk of exposure to heightened fluoride levels.

Monsoon Season

Aquifers that store groundwater get a substantial boost during the monsoon season when it rains heavily. Wells, hand pumps, and bore wells have relatively lower fluoride levels because the concentration of fluoride in the groundwater is diluted by the influx of rainwater. On the other hand, rainwater has the ability to mobilize extra fluoride in areas where geological formations and soils are rich in fluoride. This is because it can boost the leaching process from rocks and soil minerals. Hence, while dilution often lowers the fluoride concentration in monsoon water, there may be certain regions where the levels are still higher than the 1.5 mg/L limit. This variance emphasizes the need for monitoring at specific sites instead of depending only on seasonal averages.

Post-Monsoon Season

When the monsoons are over and the aquifers have had an opportunity to recharge and drain, groundwater levels level out. Typically, fluoride concentrations are in the middle range at this time, going up from monsoon levels but not quite reaching the peaks seen just before the monsoon. Factors include ongoing mineral leaching from underground rocks and groundwater extraction for agricultural, household, and industrial uses determine the degree to which seasonal fluctuations occur. During the post-monsoon period, fluoride levels in shallow aquifers may be significantly lower than they were before the rains, but in deeper aquifers where fluoride is naturally abundant, the concentrations may remain high.

Implications for Public Health

In areas where fluorosis is common, seasonal changes in fluoride concentrations pose a serious threat to public health. There is an increased risk of dental fluorosis in children and skeletal fluorosis in adults during the pre-monsoon season, even though the water fulfills safety standards during the monsoon. Children are at a higher risk of permanent enamel damage from excessive fluoride consumption during the tooth-forming years (birth to eight years old). Too much fluoride in the water over an extended



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period of time causes a variety of health problems, including discolored teeth, pitting, skeletal abnormalities, and mottled enamel.

Need for Regular Monitoring and Mitigation

Fluoride levels in various water sources must be regularly monitored throughout the year due to the fact that they might vary greatly depending on the season. In this way, we can pinpoint when the water's fluoride levels are too high and act quickly to prevent further damage. Public education regarding the dangers of excessive fluoride exposure, the installation of defluoridation equipment in individual homes and communities, the use of surface water or rainwater collection as alternative water sources, and other similar measures are all potential mitigation tactics. Health problems caused by fluoride can be mitigated with the help of nutritional therapies, such as getting enough vitamin D, antioxidants, and calcium.

When it comes to public health and water management, it's crucial to know how fluoride pollution changes with the seasons. This is particularly true in areas where groundwater is the main supply for drinking water. In the absence of such comprehensive seasonal data, risk evaluations run the danger of underestimating communities' actual fluoride exposure, which could result in avoidable health complications.

CONCLUSION

Communities that depend mostly on untreated sources for drinking and household usage are more vulnerable to the public health risks associated with fluoride poisoning of groundwater. Although small levels of fluoride are necessary for healthy teeth, long-term exposure, particularly in youth, can cause skeletal abnormalities, dental fluorosis, and other health problems. Based on the research we have, children are especially at risk since their enamel is still developing, and consuming too much fluoride during this time can lead to persistent hypo-mineralization, discolouration, and pitting.

Fluoride concentrations in groundwater are highly sensitive to seasonal changes. Because of decreased water volumes and natural leaching from fluoride-rich minerals, fluoride levels tend to be highest before the monsoon and lowest after the rains begin to fall. In order to properly identify communities at risk and advise prompt solutions, constant monitoring is necessary, as these changes show how inadequate single-season assessments are. Additional variables that influence the relationship between fluoride exposure and health hazards include geology, the environment, and socioeconomic status. An increased risk of contamination occurs in areas where aquifers are rich in fluoride, where water use is high, and where there are few options for safe drinking water. Consequently, prevention measures should take a holistic approach, combining fluoridation methods at the community and household levels with public education initiatives, dietary assistance, and water management programs guided by policy.



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Last but not least, good public health planning requires knowledge of the spatial and temporal dynamics of fluoride pollution. For correct risk evaluation, focused therapies, and long-term prevention of skeletal and dental fluorosis, it is necessary to combine seasonal surveillance with epidemiological evaluations. Reducing fluoride exposure, protecting vulnerable individuals, and ensuring access to safe drinking water in endemic locations requires coordinated actions by communities, health agencies, and governments.

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