Fluorosis: Understanding Its Causes, Strategies for Prevention, And Effective Control Measures.

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***Abstract*—Fluorosis is a slow and progressive disorder affecting our body and a serious concern to be taken into consideration and to be dealt with effectively. Fluorosis remains a critical global health issue, primarily caused by prolonged exposure to excessive fluoride levels, exceeding the permissible limit of 1.5 ppm (IS: 10500:2012). It manifests in dental, skeletal and non-skeletal forms, significantly affecting human health and quality of life. The primary sources of fluoride exposure include drinking water, agricultural produce, industrial emissions, processed foods and dental products, with groundwater being the most dominant contributor. This study presents a comprehensive assessment of fluoride contamination through the analysis of both water and urine samples, providing a dual perspective on environmental fluoride levels and human fluoride burden. Urinary fluoride concentration serves as a crucial biomarker for recent fluoride exposure, enabling a more precise evaluation of individual and community risk. The findings highlight the geogenic origins of fluoride contamination, anthropogenic contributions and dietary intake as key risk factors. The study further explores integrated prevention and mitigation strategies, including community-driven awareness programs, dietary modifications, advanced defluoridation technologies and sustainable water resource management. Additionally, it evaluates policy-driven interventions and early diagnostic approaches as essential tools for controlling fluorosis. The results underscore the necessity of continuous surveillance of fluoride levels in both environmental and biological samples, along with adaptive policy frameworks and public health initiatives. This research advocates for a multidisciplinary approach that combines technological advancements, community participation and regulatory measures to effectively mitigate the devastating impact of fluorosis on global populations**.

***Index Terms*—Fluorosis, Fluoride Contamination, Water and Urine Analysis, Biomarkers, Defluoridation, Public Health, Environmental Exposure.**

I INTRODUCTION

Fluorosis is a significant global public health concern caused by prolonged exposure to excessive fluoride levels in drinking water, food and the environment. While fluoride is essential in small amounts for maintaining dental and skeletal health, excessive intake leads to dental, skeletal and non-skeletal fluorosis, resulting in severe health and socio-economic burdens, particularly in developing regions (WHO, 2019). The condition is endemic in over 25 countries, including India, China, Kenya and Tanzania, where fluoride concentrations in drinking water frequently exceed the permissible limit due to natural geological processes and anthropogenic activities (Choubisa, 2018).

The primary route of fluoride exposure is through contaminated groundwater, which serves as the main drinking water source in many affected regions. Other sources, including industrial emissions, fluoride-rich soils, processed foods and dental products, further contribute to fluoride accumulation in the human body. Fluoride toxicity primarily affects bones and teeth, leading to dental fluorosis—characterized by enamel discoloration and structural defects—and skeletal fluorosis, which causes joint stiffness, bone deformities and chronic pain (Gupta et al., 2013). Additionally, prolonged exposure has been linked to systemic health issues, including renal dysfunction and neurological impairments.

Several factors influence fluorosis severity, including climatic conditions, socio-economic status and nutrition and population vulnerability. Children are particularly at risk due to their higher water consumption per body weight and developing skeletal systems. The economic burden of fluorosis is substantial, leading to increased healthcare costs, reduced productivity and social stigma in affected communities (Reddy et al., 2010).

Efforts to mitigate fluorosis require a multidisciplinary approach involving scientific research, policy interventions and community participation. Strategies include defluoridation technologies for safe drinking water, dietary interventions to reduce fluoride absorption and large-scale public awareness campaigns. Policy-driven mitigation programs and sustainable water resource management play a crucial role in controlling fluoride exposure (BIS, 2012). Despite existing efforts, fluorosis remains a persistent health challenge, necessitating further research into cost-effective defluoridation methods, early diagnostic approaches and region-specific prevention strategies.

This study explores the complex nature of fluorosis by analysing fluoride contamination through water and urine sample testing to assess human fluoride exposure. It examines the epidemiology, risk factors and socio-economic implications of fluorosis, alongside global and regional efforts for prevention and control. The findings emphasize the importance of an integrated, evidence-based approach combining technological advancements, policy measures and community engagement to effectively combat this public health crisis.

II MATERIAL AND METHODS

1. Study Design

The cross-sectional study was conducted in two distinct regions: one with endemic fluoride exposure and another with low fluoride exposure. The populations were selected from communities where fluoride concentrations in drinking water were known to differ, allowing for a comparative analysis of fluorosis occurrence in Groundwater and urine samples.

2. Study Area

The study involved three main groups: children aged under 18 years and adults (males and females) from the rural regions of district Nawada namely Chapri (Sirdala Block), Baseria (Sirdala Block) and Radhe Bigha (Rajauli Block).

3. Sampling Method

Samples were randomly selected from school rosters and local community lists. The sampling method aimed to minimize biasness by ensuring that all members of the population had an equal chance of selection. Stratified random sampling was applied to ensure proportional representation across different age groups and geographic locations within each region. In total, 20 children, 60 children from each sampling area and 90 adults, including 15 males and 15 females from each sampling area for urine samples were conducted. The total of 150 samples of drinking water collected, 50 from each sampling area.

4. Laboratory Analysis

The laboratory analysis was crucial in determining the fluoride concentrations in drinking water sources and urine samples. Samples were analyzed using a fluoride Ion Selective Electrode (ISE) method. This technique involves measuring the activity of fluoride ions in the sample and correlating this with the concentration of fluoride. The samples were prepared and analyzed according to standardized protocols (American Public Health Association, 2017). Duplicate measurements were taken for accuracy and the results were recorded in milligrams per liter (mg/L).

For quality control, a set of standard solutions with known fluoride concentrations was prepared and analyzed alongside the water samples. The acceptable range of error was within 5% for fluoride concentration measurement.

III RESULTS

Parameter		Ground Water	Urine		
			Male	Female	Children (under 18yrs)
Range	Min	2.26	1.8	4.27	0.868
	Max	11.1	18.2	9.64	13.01
Mean		5.296	7.75	7.02	6.48
Standard Deviation		1.65	4.53	1.86	3.93

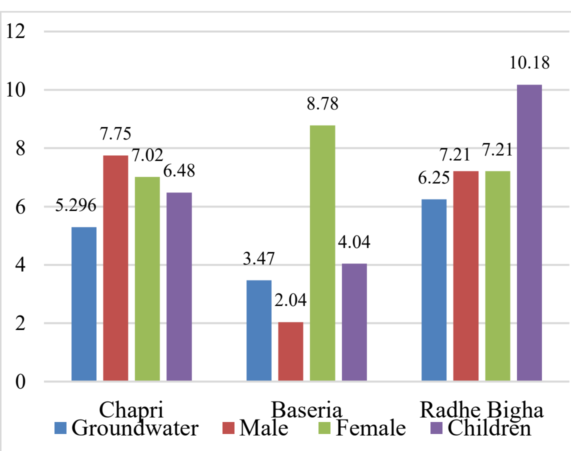
Table 1: Fluoride concentration observed at Chapri, Sirdala Block, Nawada, Bihar

Parameter		Ground Water	Urine		
			Male	Female	Children (under 18yrs)
Range	Min	1.26	2.04	6.29	1.59
	Max	6.8	5.55	14.4	11.4
Mean		3.47	2.04	8.78	4.04
Standard Deviation		1.38	2.49	3.78	2.56

Table 2: Fluoride concentration observed at Baseri, Sirdala Block, Nawada, Bihar

Parameter		Ground Water	Urine		
			Male	Female	Children (under 18yrs)
Range	Min	1.67	1.29	2.04	4.15
	Max	15.1	12.11	14.21	19.23
Mean		6.25	7.21	7.21	10.18
Standard Deviation		5.22	3.67	4.71	7.04

Table 3: Fluoride concentration observed at Radhe Bigha, Rajauli block, Nawada, Bihar



Graph 1: Fluoride concentration observed at different blocks of Nawada District depicting mean values

Fluoride Levels in Groundwater

The fluoride concentration in groundwater and urine samples collected from Chapri, Baseria and Radhe Bigha varied significantly across different demographic groups (Table 1). The findings highlight a correlation between high groundwater fluoride levels and urinary fluoride concentration, emphasizing the impact of environmental fluoride exposure on human health.

Groundwater fluoride concentrations varied across the study locations, with the highest mean value recorded in Radhe Bigha (6.25 mg/L), followed by Chapri (5.296 mg/L) and Baseria (3.47 mg/L). The maximum fluoride concentration in groundwater was recorded at Radhe Bigha (15.1 mg/L), which far exceeds the WHO permissible limit of 1.5 mg/L for drinking water. The lowest fluoride level (1.26 mg/L) was observed in Baseria, which is still slightly above the recommended safe limit.

Fluoride Levels in Urine

Urinary fluoride concentration serves as a reliable biomarker for assessing fluoride exposure in human populations. Across the study regions, significant variations were observed in urinary fluoride levels among males, females and children.

- Chapri: The highest urinary fluoride levels were recorded in females (mean: 7.75 mg/L, max: 18.2 mg/L), followed by children (mean: 7.02 mg/L) and males (mean: 5.296 mg/L). This suggests a greater accumulation of fluoride in women, which may be influenced by physiological factors and dietary habits.
- Baseria: The lowest mean urinary fluoride level (2.04 mg/L) was recorded in females, while children exhibited the highest mean (8.78 mg/L). The relatively lower fluoride burden in adults may be attributed to their diversified diet, while children, having a higher water intake per body weight, are more susceptible to fluoride toxicity.

Radhe Bigha: The highest fluoride burden was observed in children (mean: 10.18 mg/L, max: 19.23 mg/L), indicating significant exposure risk. The mean urinary fluoride levels in males (7.21 mg/L) and females (7.21 mg/L) also suggests chronic exposure.

IV CONCLUSION

The distribution of fluorine in the environment is influenced by various factors such as topography, geology, and hydrogeological conditions. Fluoride, a naturally occurring element, is commonly present in combination with other elements and can be found in water, soil, food, and numerous minerals (De et al.).

When present in drinking water at concentrations below 0.5 mg/L, fluoride may aid in preventing dental caries and contribute to the development of strong teeth and bones. However, prolonged exposure to higher concentrations, particularly through fluoridated drinking water, can lead to a variety of adverse health effects, including fluorosis. The primary source of elevated fluoride levels in groundwater is the prolonged weathering of fluoride-rich rocks and their continuous interaction with water (De et al.).

The study demonstrates a clear link between high groundwater fluoride concentrations and increased urinary fluoride levels, posing significant health risks to local populations. The findings emphasize the urgent need for fluoride mitigation strategies, particularly in highly affected regions such as Radhe Bigha. A multi-pronged approach involving water quality management, nutritional supplementation and community education is crucial for controlling fluorosis and safeguarding public health.

Fluoride toxicity mechanism

Fluoride accumulation in humans and livestock is influenced by several factors, including the route of exposure, dietary habits, digestive tract pH, and the presence of calcified tissues. Daily fluoride intake is primarily determined by its concentration in drinking water, food, and ambient air (Kabir et al., 2020). Inorganic fluoride compounds exert effects on various biological systems through a range of cellular mechanisms. Studies have shown that fluoride can interfere with cellular functions such as gene regulation, cell cycle progression, cell proliferation and migration, respiration, metabolism, ion transport, secretion, endocytosis, apoptosis or necrosis, and oxidative stress. These cellular changes are associated with numerous signaling pathways (Ahmad et al., 2022; Barbier et al., 2010; Strunecka & Strunecky, 2020).

Interestingly, the average fluoride concentration in the urine of boys was found to be higher than the fluoride concentration in drinking water, likely due to additional intake from dietary sources such as tea, milk, and vegetables. Many Other studies attributes that urinary fluoride levels elevated through food which contains bioavailable fluoride (Del Carmen et al., 2016; Paez & Dapas, 1983; Rango et al., 2014; Szymaczek & Lewicka, 2005). Moreover, a dental fluorosis survey indicated that a majority of subjects exhibited signs of the condition.

Fluoride Removal or Defluoridation Techniques

In addition to field-based data collection, strategies for the prevention and control of fluorosis were evaluated. These strategies included:

1. Community Education: A community outreach program was implemented to raise awareness about the risks of overexposure to fluoride and the importance of reducing fluoride intake. Educational materials were distributed in the endemic and non-endemic regions, targeting parents, teachers and health workers. Workshops and seminars were conducted to inform the community about safe water consumption practices, the importance of regular dental check-ups, and alternative sources of drinking water.
2. Fluoride-Reducing Technologies: The study also investigated the use of water filtration systems designed to remove excess fluoride from drinking water. The effectiveness of various filtration technologies, such as activated alumina and reverse osmosis systems, was evaluated in pilot projects within affected communities. Water samples before and after filtration were analyzed to measure fluoride reduction efficiency.

The global scarcity of clean and safe drinking water is a pressing concern, and fluoride contamination significantly contributes to this crisis by posing serious health risks. Elevated fluoride levels in groundwater have emerged as a major public health issue worldwide (Kumar & Chawla, 2020). To address this, various defluoridation techniques have been developed and employed to remove excess fluoride from drinking water. These include ion exchange, precipitation, membrane filtration processes, adsorption, as well as phyto- and bioremediation methods (Kumar & Chawla, 2020). Among these, reverse osmosis (RO), electrodialysis, and distillation are considered advanced treatment technologies for fluoride removal. Traditional methods such as the use of bone charcoal, the Nalgonda technique, activated alumina, and clay-based filtration have also been widely applied for defluoridation (Mobeen & Kumar, 2017). One cost-effective and efficient method is precipitation through coagulation, where suspended charged particles are neutralized and aggregated into larger particles that settle out. The efficiency of this process depends on factors such as pH and temperature. Lime [Ca $(OH)_2$] and alum [$Al_2(SO_4)_3 \cdot 18H_2O$] are the most traditionally and widely used compounds for fluoride removal (Adhikari et al., 2019; Yadav et al., 2018). A comprehensive study conducted in three severely fluorosis-affected habitations of Rajauli block, Nawada district, Bihar, examined the impact of interventions carried out in two phases—before and after the supply of fluoride-safe potable water. The intervention also included the incorporation of Moringa leaf powder in daily meals as a nutritional supplement for fluorosis patients. The findings demonstrated a significant improvement in health conditions, as evidenced by reduced body pain, enhanced appetite, improved mental and physical well-being, and even the ability of previously bedridden patients to walk with assistance. These outcomes underscore the effectiveness of the Integrated Fluorosis Mitigation Programme, which was further strengthened by extensive awareness and community engagement initiatives aimed at educating residents about the dangers of fluoride-contaminated water and the benefits of using fluoride-safe alternatives (Bihari Singh et al.).

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