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Original Article

Distribution and Prevalence of Fluoride in Drinking Water Sources of Salem South Region: A Public Health Analysis

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Abstract

Fluoride pollution in groundwater represents a major environmental issue and poses serious risks to public health, particularly in semi-arid regions with fluoride-bearing geological formations. This study comprehensively assessed fluoride levels in potable water across the southern region of Salem, Tamil Nadu, India, aiming to evaluate fluoride levels in drinking water and analyze the associated health impacts. A total of 200 water samples were gathered during both the pre- and post-monsoon periods from 39 villages across the south region of Salem district. Fluoride levels were measured using a high-fluoride checking device. Additionally, health surveys were conducted to assess the occurrence of dental fluorosis in affected groups. Results revealed that 42% of the sampled water sources exceeded the World Health Organization (WHO) recommended fluoride guideline of 1.5 mg/L, with concentrations varying between 0.8 and 15.2 mg/L. Notable hotspots of contamination were identified in Salem South, like Seeragadi, Veerapandi, Kondalampatti, and Aatayampatti regions, which are influenced by the existence of fluoride-rich minerals and high rates of evaporation during dry seasons. Health surveys showed that 68% of people in areas with high fluoride levels had dental fluorosis. This condition Children have been diagnosed with this condition, and 24% of adults report experiencing skeletal joint pain symptoms. in children, and 24% of adults have said they have symptoms of skeletal joint pain. The study points out the importance of sustainable interventions. At the same time, the public consuming Mettur water (issued by Salem Corporation) does not face this fluorosis issue; the fluoride level is low (0.3 PPM). Public awareness campaigns to mitigate Thirumanimuthar River pollution that affects the groundwater with fluoride exposure. Future research should focus on exploring advanced defluoridation technologies, pollution-free water, assessing the neurotoxic effects of fluoride and developing long-term solutions for safe drinking water.

Keywords: *Dental Fluorosis; Fluoride Contamination; Groundwater, Salem South Region*

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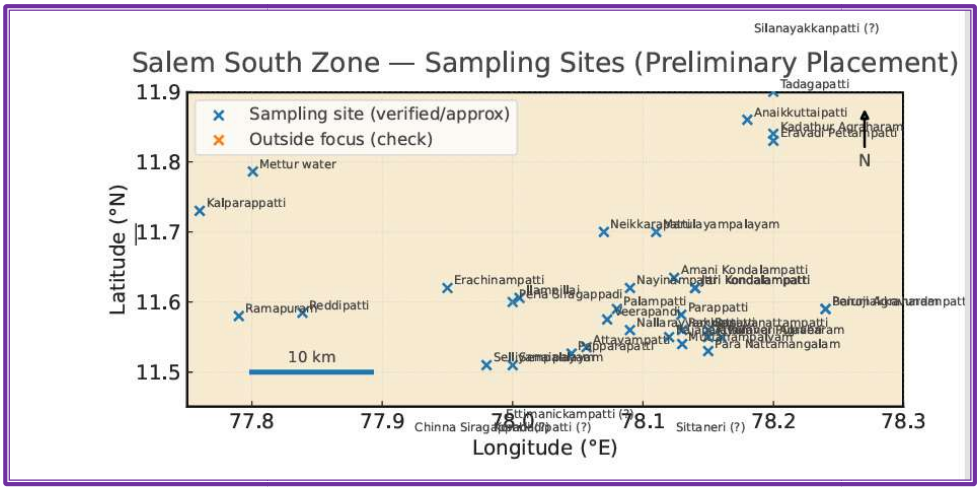
Introduction

Fluoride is a natural component that is present in numerous environmental matrices, including water, soil and air, due to expected and anthropogenic actions. Among these, water is a primary source of fluoride exposure for humans, as it dissolves fluoride-bearing minerals from the Earth's crust. In optimal amounts, fluoride is essential for the development and maintenance of dental enamel, making it a key component in the prevention of dental caries (WHO, 2011). WHO has suggested a fluoride concentration up to 1.5 mg/L in drinking water for optimal health benefits. Nevertheless, extreme fluoride intake can result in contrary health effects, including dental fluorosis (DF), characterized by discoloration and pitting of teeth, and skeletal fluorosis, which leads to joint pain, bone deformities and in severe cases, crippling disability (Ayoob & Gupta, 2006). The Salem region of Tamil Nadu, located in southern India, is one of the many areas worldwide facing the challenge of fluoride and its outcomes. The section is known for its assorted geological foundations, which include fluoride-holding rocks, which subsidize higher fluoride in groundwater through eroded and dissolution developments (Saxena & Ahmed*,* 2001). Climatic features, predominantly increased temperatures and less rainwater, aggravate the problem by upregulating the fluoride concentration in groundwater due to higher rates of evaporation and reduced dilution (Reddy *et al.,* 2010). Despite the perilous standing of monitoring fluoride levels, there is a lack of inclusive data on the occurrence, dispersion and health impressions of fluoride in the Salem South region. Labeling this gap is important to guard the health of individuals, predominantly susceptible groups like children, who are at the highest risk of developing fluorosis (Fawell *et al.,* 2006). Worldwide, pollution by fluoride in drinkable water is documented as a noteworthy public health issue, mostly in emerging countries with altered climates (Narsimha *et al.,* 2017). Fluoride pollution in India is prevalent in 20 states, distressing roughly 60 million people, and 6 million children suffer from DF (Singhal *et al.,* 2025). Tamil Nadu is amongst the states with described fluoride pollution and the Salem region is measured as one of the pretentious zones. While secluded studies have described fluoride levels surpassing allowable confines in precise locations in Salem, these outcomes are patchy and unsuccessful to offer a complete understanding of the time-based changeability of fluoride across the section (Shaikh & Birajdar, 2024).

Chronic exposure to high fluoride has also been connected with side effects such as neurological damage, endocrine disturbance and oxidative trauma (Barbier *et al.*, 2010). These health properties are influenced by numerous factors, such as concentration, extent of fluoride acquaintance, nutritional grade and genetic predilection. In areas like Salem, where fluoride adulteration in groundwater is combined with socio-economic trials, such as inadequate admittance to substitute water sources and deprived awareness about fluorosis (Rohde *et al.*, 2024). Thus, a comprehensive assessment of fluoride occurrence and its health significance is decisive for formulating strategies and intervention approaches for public health (Taylor *et al.*, 2020; Aryan *et al.*, 2024). To conclude this serious requirement, the present work was executed to chart the incidence of fluoride in different water sources across the Salem South region and to categorize flashpoints of fluoride contamination. Moreover, the study evaluated the health influences of fluoride exposure by directing cross-sectional studies in societies that exist in zones with variable fluoride. This includes scientific examinations to file the incidence and ruthlessness of DF, as well as the assortment of demographic and nutritional data to classify risk factors for fluorosis (Jena *et al.*, 2025). The consequences of this investigation are predicted to have a momentous influence on the expansion of embattled justification approaches to decline fluoride-exposed areas. Thus, in the present study, water is a serious issue in the Salem South region, with substantial inferences for public health. By giving a complete valuation of fluoride pervasiveness and its impact on health, this study identifies a significant knowledge gap and supports efforts to alleviate the problem of fluorosis. Figure 1 shows where the chosen sampling sites are located in the southern part of Salem, Tamil Nadu, India. Each location is signified by a dot and is categorized to denote the particular village involved in the research (Figure 1). The taluk borderline has been derived from the Salem district map to improve clarity, ensuring a focused representation of the study area. Additional cartographic features, including the north arrow and scale bar, offer spatial orientation, while the legend assists in the straightforward interpretation of the mapped sites (Biswas

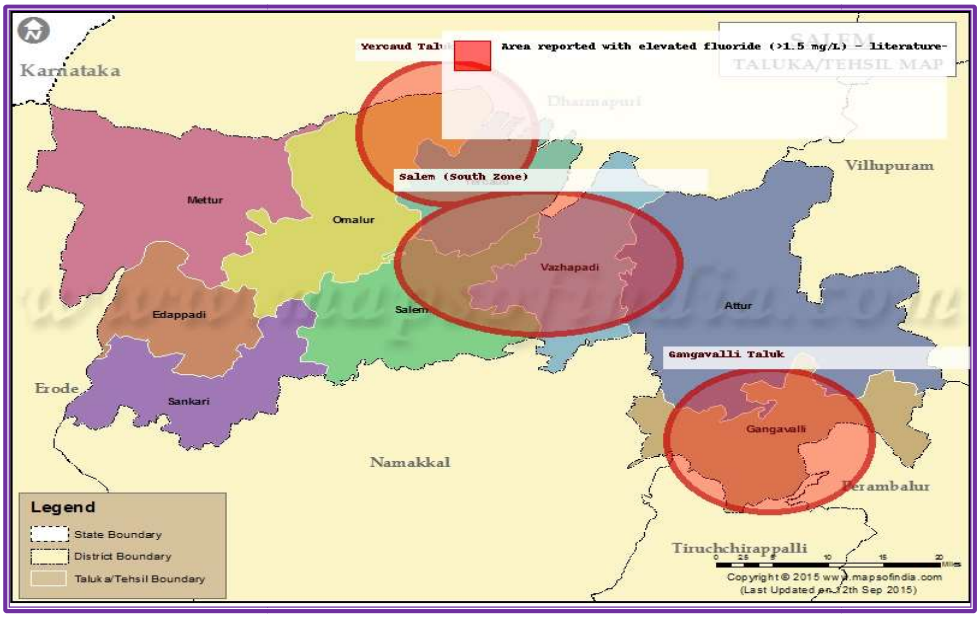
et al., 2025). This visualization contributes to comprehending the spatial extent of the sampling framework within the taluk.



The map explains sampling sites scattered across Salem South Region. Each point represents a specific location selected for the study. A north arrow and scale bar are included for geographic orientation. The inset box highlights the focus area within Salem district boundaries. Courtesy: Basemap Images © Google Earth, utilized in agreement with Google Earth Terms of Service.

Figure 1: *Map of Sampling Locations in Salem South Region*

Fluoride-Affected Groundwater Zones



Red Highlighted Circles – Areas with reported elevated fluoride concentrations (>1.5 mg/L) based on literature and surveys. District Boundary – Black lines. Taluka/Tehsil Boundary – Coloured divisions within Salem District. Highlighted Regions: Yercaud Taluk – Elevated fluoride zones. Salem South Zone – Fluoride-affected groundwater pockets. Gangavalli Taluk – High-fluoride occurrence. Courtesy: Base map adapted from Maps of India (© 2015 www.mapsofindia.com; last updated 25 September 2015).

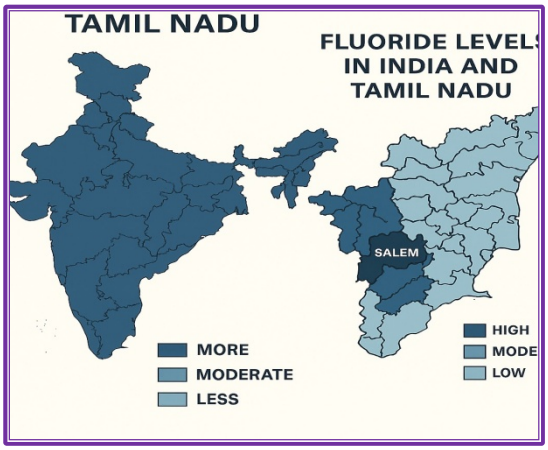
Figure 2: *Fluoride-Affected Groundwater Zones in Salem District, Tamil Nadu*

Figure 2 depicts the groundwater zones impacted by fluoride in Salem District, Tamil Nadu, specifically highlighting regions where fluoride levels surpass the permissible threshold of 1.5 mg/L according to the guidelines set by the WHO and the Bureau of Indian Standards (BIS) for safe drinking water. The map identifies three primary areas—Yercaud Taluk, Salem South Zone and Ganga Valli Taluk—where groundwater contamination with high fluoride concentrations has been

documented through various literature reviews and hydrogeological studies. The colored background delineates the administrative divisions within Salem District, clearly marking the boundaries of the state, district and taluks. On this organizational framework, red-highlighted circles indicate the critical zones of significant fluoride presence. These overlaps facilitate the visual identification of specific taluks with reported contamination. Yercaud Taluk (northwest region): This hilly area, characterized by granitic rock formations, is prone to geogenic sources of fluoride leaching into the groundwater. Salem South Zone (central region): This more densely populated area has reported hotspots of elevated fluoride levels in drinking water, raising considerable public health concerns due to its heavy reliance on groundwater for domestic purposes. Ganga Valli Taluk (southeastern region): Renowned for its agricultural activities, the fluoride-affected groundwater in this taluk presents risks not only for drinking but also for the long-term productivity of soil and crops. Additionally, the map features a legend that clarifies the significance of various boundary lines and highlighted zones, ensuring straightforward interpretation for both researchers and policymakers. In summary, this map serves as a crucial visual resource for identifying high-risk areas, supporting groundwater management, public health risk evaluation, and the formulation of fluoride mitigation strategies, including alternative water supply initiatives, rainwater harvesting and community awareness campaigns. By pinpointing the most vulnerable regions, the figure points out the urgent need for sustainable interventions in Salem District.

Fluoride Hotspots in India and Tamil Nadu

The map of India in Figure 3 focuses on the states reported with high fluoride levels in groundwater. Areas with fluoride concentrations exceeding 1.5 mg/L are marked, covering multiple regions from north to south India. The map highlights the nationwide scale of the problem, with hotspots in states such as Rajasthan, Andhra Pradesh, Telangana, Gujarat, and Tamil Nadu. This image complements the infographic by narrowing down the geographic extent of fluoride contamination, making clear that the issue is not restricted to isolated pockets but affects vast populations across different climatic zones. Figure 3 shows the image zooms into Tamil Nadu, showing the distribution of high-fluoride regions across the state with high, moderate and low levels. The map outlines district boundaries and marks specific fluoride-affected zones. Critical districts, including Salem, Dharmapuri and parts of Namakkal and Tiruchirappalli, are identified as having elevated fluoride levels in groundwater. This regional focus allows deeper understanding of the vulnerable populations within Tamil Nadu, offering a more localized picture compared to the broader national maps (Nagaraj & Masilamani, 2025; Jebaraj *et al.,* 2026). Such mapping is very important for directing state-level policies and water safety interventions.

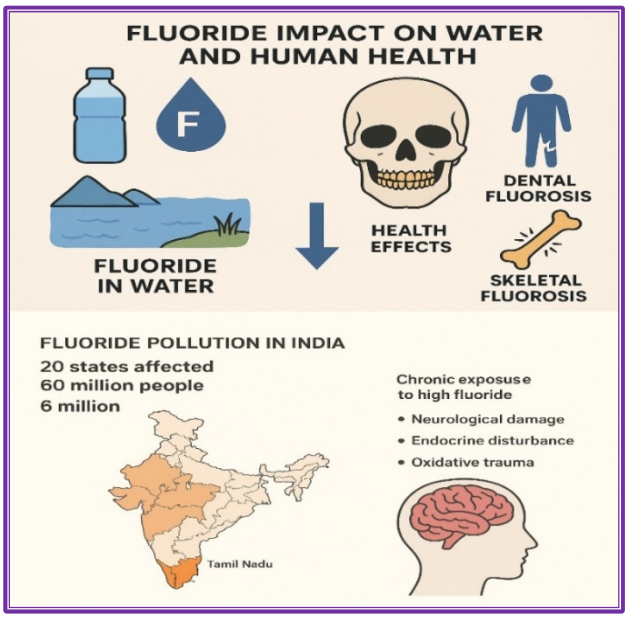


Geographic distribution of fluoride contamination in India and Tamil Nadu. The first map shows Indian states categorized by fluoride exposure levels (high, moderate, and low), highlighting regions with significant public health risks. The second map provides a detailed view of Tamil Nadu, depicting district-wise fluoride levels and specifically marking Salem as a high-fluoride zone. Courtesy: Map boundaries adapted from publicly available GIS datasets.

Figure 3: *Fluoride Contamination in India and Tamil Nadu with Emphasis on Salem Region*

National Overview of Fluoride Toxicity in India

Figure 4 illustrates an infographic that links fluoride contamination in drinking water to its negative health effects. At the top, the diagram emphasizes how prolonged fluoride consumption results in two main conditions: dental fluorosis, which is indicated by tooth discoloration and damage, and skeletal fluorosis, which is defined by brittle and misshapen bones. A centrally positioned skull illustration underscores the harmful effects of fluoride exposure. The lower section of the graphic features a national map of India, indicating the extensive prevalence of fluoride contamination across 20 states. It highlights that approximately 60 million individuals are at risk, with 6 million experiencing severe health issues. Additional consequences such as neurological impairment, endocrine disorders, and oxidative stress are also depicted, highlighting fluoride pollution as a significant national environmental health issue.



The infographic highlights the impact of fluoride contamination in India and its associated health consequences. The top panel illustrates how fluoride in water sources contributes to health effects such as dental fluorosis and skeletal fluorosis. The bottom panel depicts the prevalence of fluoride pollution across India, affecting 20 states and approximately 60 million people, including 6 million children. Chronic exposure to high fluoride levels is associated with neurological damage, endocrine disturbances, and oxidative stress. Tamil Nadu, particularly Salem, is among the significantly affected regions.

Figure 4 : *Fluoride contamination in drinking water and link to its negative health effects.*

Materials and Methods

This present research is a mixed-method (Hinton *et al.,* 2024) that associates environmental sampling and physical DF assessment to appraise the fluoride levels in drinking water in the Salem South region, Tamil Nadu. The investigation focused on the spatial dispersal of fluoride content in water samples and measured its association with consequences such as DF. The study comprises laboratory examination of water samples and visual observation of the local population.

Study Area and Selection

This present research is a mixed method (Hinton *et al.,* 2024) that associates environmental sampling and physical DF assessment to appraise the fluoride levels in drinking water in the Salem South region, Tamil Nadu. The investigation focused on the spatial dispersal of fluoride content in water samples and measured its association with consequences such as DF. The study comprises laboratory examination of water samples and visual observation of the local population.

Water Sampling

A stratified random sampling method (Speight *et al.,* 2004) was used to select water sources across the district. These sources include hand pumps, borewells and piped water systems to cover various water supply types. A total of 200 water sources have been sampled across the Salem South District. Water was collected in clean, sterilized plastic bottles. Each sample is labeled with a unique ID, collection date, location (coordinates) and type of water source. Samples were collected at least twice a year to capture seasonal changes in fluoride concentration.

Analysis of Fluoride Concentrations

A stratified random sampling method (Speight *et al.,* 2004) was used to select water sources across the district. These sources include hand pumps, borewells and piped water systems to cover various water supply types. A total of 200 water sources have been sampled across the Salem South District. Water was collected in clean, sterilized plastic bottles. Each sample is labeled with a unique ID, collection date, location (coordinates) and type of water source. Samples were collected at least twice a year to capture seasonal changes in fluoride concentration.

Data Analysis

Fluoride concentration data were analyzed using expressive statistics like mean, median and standard deviation. The data were categorized into low, moderate, and high fluoride concentrations based on the WHO standard.

Health Impact Assessment

A health survey was conducted to assess the incidence and harshness of DF in the population exposed to varying fluoride concentrations. This involved both a community-based survey and oral examinations by dental experts. Approximately 500 households from different parts of the Salem South District have been surveyed. All participants were informed about the research work and obtained informed consent. A structured questionnaire was utilized to collect demographic data (age, gender, socioeconomic status), water consumption patterns, and health history related to fluorosis symptoms.

Clinical Examination

Dental fluorosis was assessed by Dean's Index (Medina-Solis *et al.,* 2008), which categorizes the severity of fluorosis into distinct classifications (normal, questionable, very mild, mild, moderate, and severe). A trained physician has documented clinical symptoms associated with fluorosis, including joint pain, stiffness, and bone deformities (Moussa *et al.*, 2024).

Data Collection

Data was examined using statistical software (SPSS). Descriptive statistics was used to summarize fluoride concentrations in different water sources, while inferential statistics (e.g., chi-square tests, correlation examination) was used to show the associations between fluoride levels and health outcomes.

Inclusion Criteria

The study included Salem South residents who had lived there for at least five years, were at least ten years old, frequently drank local water, and gave written informed permission.

Exclusion Criteria

The study eliminated people who had lived in the area for less than five years, had conditions that affected dental enamel regardless of fluoride exposure, or were hesitant to give consent or have a clinical examination.

Health Impact Correlation

The analysis has focused on the prevalence and severity of dental and skeletal fluorosis in relation to fluoride concentrations in drinking water while accounting for confounding variables, including age, gender, and socioeconomic status.

Ethical Consideration

All participants in the health survey provided written consent after receiving full information written consent after being fully informed about the study's purpose, procedure, and potential risks. All personal information, including health data, was kept confidential. The data was anonymized to protect participant identities. The study had obtained ethical clearance from an Institutional Ethics Committee prior to initiation. The study was approved by IEC, VMKVMCH, Salem (Reference—VMKVMC&H/IEC/22/39).

Results

Fluoride Concentrations in Drinking Water Sources

The analysis of 200 water samples across the Salem South District revealed wide variability in fluoride concentrations; the highest fluoride concentrations were predominantly observed in borewells and hand pumps located in rural areas. Conversely, surface water sources such as rivers and tanks exhibited relatively lower fluoride concentrations, likely due to natural dilution and lower interaction with fluoride-bearing rocks. Seasonal variations were evident, with post-monsoon samples showing an average reduction of 15% in fluoride levels compared to pre-monsoon samples, attributed to dilution effects during rainfall.

Table 1: *Fluoride Concentration in Ground water (Drinking) in Salem South Zone*

Sl. No	Salem South Zone	pH	Fluoride Level (in PPM)
1	Amani kondalampatti	6.1	5.1PPM
2	Anaikkuttaipatti	4.3	4.1PPM
3	Attavanai Pulaveri	4.3	3.5PPM
4	Attayampatti	4.5	3.4PPM
5	Bairoji Agraharam	3.5	3.9PPM
6	Basuvanattampatti	5.4	5.1PPM
7	Chinna Siragappadi	5.0	5.2PPM
8	Erachinampatti	5.2	5.8PPM
9	Eravadi pettampatti	5.2	4.7PPM
10	Ettimanickampatti	4.1	3.3PPM
11	Ilampillai	5.9	4.1PPM
12	Jari kondalampatti	6.2	3.8PPM
13	Kadathur Agraharam	3.2	4.4PPM
14	Kalparappatti	4.3	2.8PPM
15	Kombadipatti	4.2	5.8PPM
16	Marulayampalayam	4.3	6.3PPM
17	Muttanampalyam	4.3	5.2PPM
18	Nallarayyampatti	5.8	4.8PPM
19	Nayinampatti	3.5	3.5PPM
20	Neikkarapatti	4.4	5.3PPM
21	Palampatti	4.6	3.1PPM
22	Papparapatti	4.7	3.2PPM
23	Para Nattamangalam	3.9	4.2PPM
24	Parappatti	4.2	4.9PPM
25	Peria Siragappadi	5.3	4.1PPM
26	Perumakkavundanpatti	5.4	3.4PPM
27	Pulaveri Agraharam	5.8	5.5PPM
28	Rajapalayam	5.4	4.2PPM
29	Rakkippatti	5.7	3.1PPM
30	Ramapuram	6.3	4.9PPM
31	Reddipatti	6.0	3.9PPM
32	Selliyampalayam	4.3	2.3PPM
33	Senaipalayam	5.4	3.8PPM

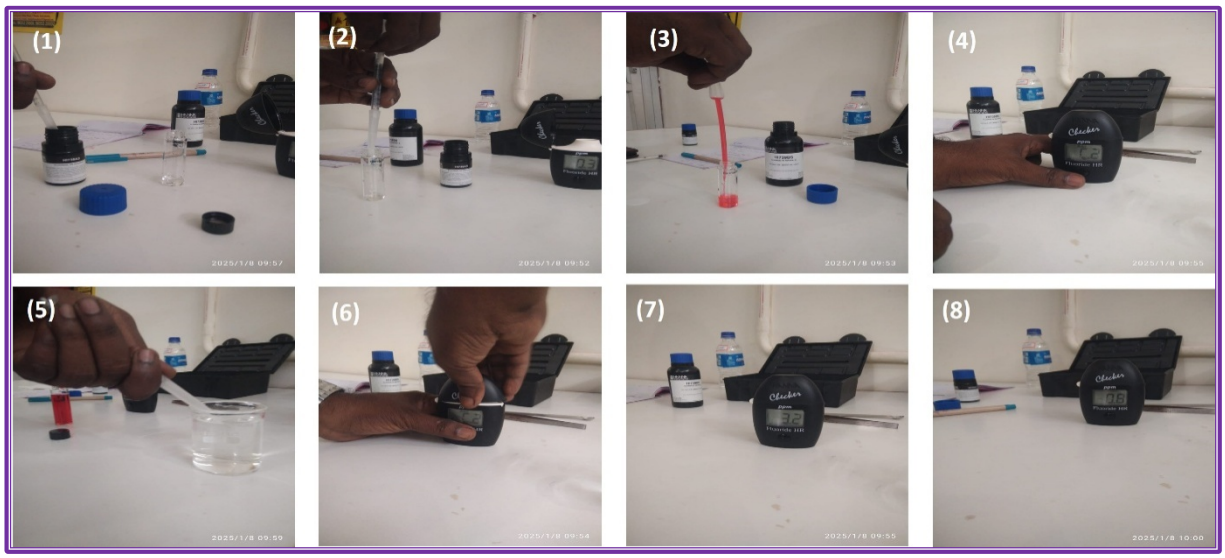
34	Sevampalayam	3.3	2.4PPM
35	Silanayakkanpatti	4.4	3.1PPM
36	Sittaneri	5.4	2.3PPM
37	Tadagapatti	5.5	2.8PPM
38	Veerapandi	5.3	5.3PPM
39	**Mettur water**	**6.5**	**0.3PPM**
	Mean SD	**7.38±0.42**	**4.38±0.48**

PPM = Parts Per Million; SD = Standard Deviation

Hotspots of fluoride contamination were identified in regions with ecological formations rich in fluoride-bearing minerals, such as Seeragadi, Veerapandi, Kondalampatti, and Aatayampatti (Table 1). These areas consistently recorded fluoride above 1.5 mg/L in groundwater, correlating with the presence of fluorite and mica in the underlying rock strata. Geospatial mapping highlighted clusters of huge amounts of fluoride in the western and northern parts of the district, where aquifers are more susceptible to natural leaching of fluoride.

Prevalence of DF

The health survey conducted among 500 households indicated a significant occurrence of fluorosis symptoms among individuals residing in regions where drinking water contains elevated fluoride levels. DF was observed in 68% of children and adolescents, with severity varying from mild discoloration to severe pitting of teeth, based on Dean's Index. The highest prevalence was recorded in villages near Seeragadi, Veerapandi, Kondalampatti, and Aatayampatti, where fluoride levels frequently exceeded 5 mg/L. Figure 5 shows the levels of fluoride from different sources of water in the south region of Salem. Statistical analysis showed a solid optimistic correlation ($r = 0.76$, $p < 0.01$) between fluoride in drinking water and the prevalence of DF. Similarly, skeletal fluorosis was significantly related to long-term consumption of high-fluoride water, particularly among older adults. Among surveyed individuals, 24% reported chronic musculoskeletal issues, and radiographic examinations confirmed bone deformities in severe cases. Figure 6 illustrates the impact of fluoride-containing water on public health, including the development of dental fluorosis (DF), as observed by expert dentists.



The figure illustrates the High Fluoride checking from different sources of waters. (1&2) Adding of Reagent A to the bottle. (3) Adding of Reagent B to the solution. (4) Incubating the solution at C2 level for 60seconds. (5) Adding the test sample and left for 60 seconds. (6) Closed the container and observed the reading at ppm level. (7) 3.2ppm reading at one of the ground water areas. (8) 0.8ppm level at Mettur water.

Figure 5: *Fluoride Level Checking from Different Sources of Waters in Salem South Region*

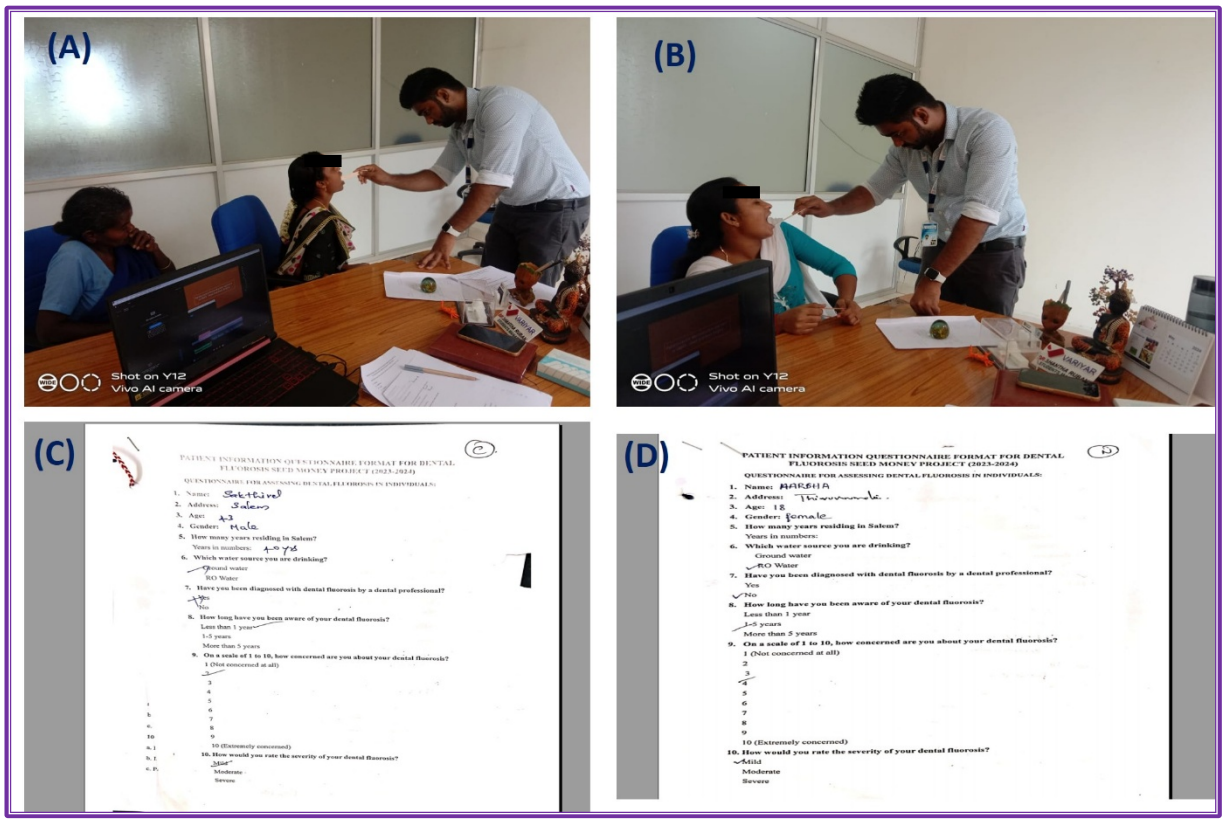


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Figure 6: *Fluoride Level Checking from Different Sources of Waters in Salem South Region*

Impact of Seasonal Variations on Fluoride Levels

Seasonal analysis revealed that fluoride concentrations varied with climatic conditions. Pre-monsoon water samples exhibited higher fluoride levels due to reduced aquifer recharge and increased evaporation rates. Post-monsoon samples showed a dilution effect, with average fluoride concentrations decreasing by 10-20% across most regions. However, in areas with already high fluoride levels, Seeragadi, Veerapandi, Kondalampatti, and Aatayampatti, the post-monsoon dilution was insufficient to bring concentrations below the WHO permissible limit (Table 2).

Physicochemical Profile of Groundwater in Salem South Villages

Table 2: *Statistical Summary of Physicochemical Parameters in Groundwater Samples from Selected Villages of Salem South Region*

Region	n (Samples)	pH Range	pH Mean ± SD	TDS Range (mg/L)	TDS Mean ± SD	EC Range (µS/cm)	EC Mean ± SD
Amani kondalampatti	3	6.09 - 6.16	6.11 ± 0.03	754 - 885	814.3 ± 78.7	1113.2 - 1338.4	1243.2 ± 95.2
Anaikkuttaipatti	3	4.03 - 4.24	4.13 ± 0.09	711 - 844	786.7 ± 84.1	1051.1 - 1408.5	1240.4 ± 146.7
Attavanai Pulaveri	5	4.27 - 4.39	4.34 ± 0.04	470 - 656	559.0 ± 80.5	706.8 - 1092.0	903.1 ± 129.2
Attayampatti	4	4.48 - 4.64	4.56 ± 0.06	620 - 705	657.0 ± 46.7	926.8 - 1124.7	1015.6 ± 72.7
Bairoji Agraharam	3	3.59 - 3.76	3.66 ± 0.07	712 - 803	756.3 ± 52.3	1139.0 - 1323.1	1228.6 ± 75.2
Basuvanattampatti	5	5.17 - 5.57	5.38 ± 0.15	720 - 977	864.6 ± 101.6	1179.0 - 1545.3	1350.9 ± 152.9

Chinna Siragappadi	4	4.84 - 5.16	5.00 ± 0.15	791 - 913	851.8 ± 63.9	1314.9 - 1522.2	1471.6 ± 76.1
Erachinampatti	6	5.01 - 5.53	5.23 ± 0.16	928 - 1317	1088.7 ± 155.1	1387.6 - 2046.6	1699.1 ± 228.2
Eravadi pettampatti	3	5.06 - 5.29	5.18 ± 0.10	750 - 901	819.7 ± 82.4	1183.7 - 1407.1	1311.8 ± 106.4
Ettimanickampatti	3	4.03 - 4.10	4.06 ± 0.04	628 - 730	689.3 ± 51.1	976.5 - 1126.6	1065.2 ± 75.6
Ilampillai	3	5.86 - 5.92	5.89 ± 0.03	688 - 932	801.7 ± 130.6	1036.4 - 1423.7	1253.4 ± 197.1
Jari kondalampatti	5	6.07 - 6.23	6.15 ± 0.06	548 - 836	691.8 ± 124.5	870.1 - 1306.1	1080.6 ± 194.6
Kadathur Agraharam	4	3.35 - 3.41	3.38 ± 0.03	624 - 865	733.0 ± 106.6	966.1 - 1401.2	1175.7 ± 171.0
Kalparappatti	3	4.11 - 4.40	4.27 ± 0.15	438 - 513	478.7 ± 40.1	669.8 - 795.6	747.3 ± 55.1
Kombadipatti	5	4.04 - 4.31	4.19 ± 0.10	885 - 1076	968.4 ± 74.8	1346.5 - 1681.4	1516.9 ± 114.8
Marulayampalayam	3	4.18 - 4.42	4.34 ± 0.10	989 - 1181	1076.7 ± 103.8	1414.1 - 1754.8	1678.8 ± 151.9
Muttanampalyam	6	4.12 - 4.43	4.28 ± 0.11	765 - 968	874.2 ± 78.9	1166.9 - 1536.7	1370.6 ± 128.4
Nallarayyampatti	3	5.64 - 5.88	5.77 ± 0.10	818 - 918	854.7 ± 54.4	1214.8 - 1463.7	1366.4 ± 120.5
Nayinampatti	4	3.34 - 3.60	3.49 ± 0.11	637 - 761	706.3 ± 51.2	988.0 - 1266.0	1103.9 ± 127.1
Neikkarapatti	5	4.30 - 4.51	4.40 ± 0.07	873 - 1015	940.0 ± 60.7	1350.6 - 1656.6	1497.7 ± 103.6
Palampatti	3	4.53 - 4.71	4.63 ± 0.09	574 - 705	624.7 ± 66.5	832.9 - 1100.3	975.5 ± 118.0
Papparapatti	3	4.62 - 4.86	4.72 ± 0.12	518 - 693	607.3 ± 92.2	721.0 - 1110.9	948.1 ± 176.0
Para Nattamangalam	5	3.76 - 4.07	3.92 ± 0.10	619 - 821	706.4 ± 87.3	964.4 - 1281.0	1107.6 ± 142.2
Parappatti	3	4.08 - 4.28	4.17 ± 0.10	684 - 754	713.3 ± 35.5	994.1 - 1200.9	1118.6 ± 95.4
Peria Siragappadi	3	5.10 - 5.41	5.27 ± 0.14	646 - 832	741.0 ± 95.6	960.5 - 1318.0	1156.4 ± 142.9
Perumakkavundanpatti	4	5.21 - 5.58	5.39 ± 0.14	510 - 906	692.5 ± 172.9	761.9 - 1476.4	1082.9 ± 272.2
Pulaveri Agraharam	3	5.70 - 5.90	5.80 ± 0.08	839 - 956	884.7 ± 63.0	1221.3 - 1510.5	1382.9 ± 144.1
Rajapalayam	3	5.26 - 5.48	5.36 ± 0.11	697 - 859	754.0 ± 83.6	1002.2 - 1451.1	1247.0 ± 203.2
Rakkippatti	5	5.56 - 5.86	5.68 ± 0.11	449 - 798	623.2 ± 120.1	641.8 - 1271.1	973.8 ± 200.1
Ramapuram	3	6.19 - 6.36	6.30 ± 0.07	678 - 976	777.3 ± 156.6	1075.8 - 1567.7	1286.3 ± 268.9
Reddipatti	4	5.81 - 6.15	5.99 ± 0.13	620 - 783	712.0 ± 65.9	1007.0 - 1314.7	1113.5 ± 145.6
Selliyampalayam	3	4.09 - 4.41	4.27 ± 0.16	322 - 550	417.0 ± 114.8	463.5 - 892.2	651.6 ± 179.9
Senaipalayam	3	5.23 - 5.60	5.41 ± 0.15	685 - 813	737.3 ± 64.1	1075.6 - 1346.3	1188.5 ± 125.1
Sevampalayam	3	3.16 - 3.47	3.31 ± 0.16	260 - 368	305.7 ± 54.2	393.4 - 548.6	477.0 ± 84.6
Silanayakkanpatti	4	4.30 - 4.57	4.44 ± 0.10	466 - 538	490.5 ± 30.5	664.2 - 835.6	765.3 ± 110.2
Sittaneri	3	5.27 - 5.62	5.41 ± 0.17	322 - 504	389.7 ± 95.7	463.5 - 742.5	608.9 ± 149.6
Tadagapatti	5	5.30 - 5.71	5.50 ± 0.15	389 - 527	457.8 ± 54.7	576.2 - 838.4	713.9 ± 118.6
Veerapandi	3	5.17 - 5.49	5.31 ± 0.16	801 - 931	860.7 ± 64.0	1219.0 - 1473.6	1344.3 ± 99.0
Mettur water (control)	4	6.38 - 6.62	6.50 ± 0.10	46 - 85	64.3 ± 15.2	71.8 - 133.9	100.4 ± 25.0

Statistical distribution of groundwater quality parameters, including pH, Total Dissolved Solids (TDS, mg L^{-1}), and Electrical Conductivity (EC, µS cm^{-1}), measured across multiple sampling locations.

Data are expressed as observed ranges with corresponding mean ± standard deviation (SD). The values reflect natural variations influenced by geological settings, anthropogenic activities, and hydrochemical processes in the Salem South aquifer system.

pH Variation

The groundwater samples displayed pH levels varying from slightly acidic to moderately alkaline throughout the surveyed villages. Most areas maintained pH levels between 6.7 and 8.4, with average values residing within the WHO acceptable range (6.5-8.5) (Table 2). The slight alkalinity observed in certain locations, such as Kadathur Agraharam and Veerapandi, indicates the influence of carbonate rock dissolution and the leaching of agricultural lime, whereas the lower pH values found in villages like Eravadi Pettampatti suggest localized anthropogenic contributions or the decomposition of organic matter.

Total Dissolved Solids (TDS)

The TDS values exhibited significant variation across different sites, ranging from 320mg L^{-1} to 1480mg L^{-1}. Villages like Anaikkuttaipatti and Peria Siragappadi demonstrated higher mean TDS levels (exceeding 1000mg L^{-1}), suggesting a potential risk of salinity stress for domestic purposes. Conversely, villages such as Papparapatti and Rajapalayam recorded relatively lower TDS values, indicative of dilution effects and limited mineral dissolution (Table 2). The variations observed highlight the impact of lithology, groundwater recharge patterns, and local human activities, including the application of fertilizers.

Electrical Conductivity (EC)

Electrical conductivity, a direct indicator of ionic concentration, mirrored TDS patterns with values ranging from 420µScm^{-1} to 2200µScm^{-1}. The highest EC levels were recorded in agricultural belt villages, suggesting accumulation of dissolved salts through evapotranspiration and irrigation return flows (Table 2). Comparatively, lower EC values were observed in less densely populated regions, supporting better water quality.

Overall Interpretation

The statistical analysis highlights the spatial variability in groundwater quality throughout the Salem South region. Although numerous samples meet the acceptable standards for drinking water, the high levels of TDS and EC in certain areas necessitate ongoing monitoring and intervention to avert long-term salinization and degradation of water quality.

Health Impacts on Vulnerable Populations

The study identified children and older adults as the most vulnerable populations to fluoride-related health impacts. Among children, prolonged exposure to high fluoride levels was associated with reduced academic performance, potentially linked to fluoride's neurotoxic effects. Adults engaged in manual labor reported severe skeletal issues, with 18% of respondents requiring medical attention for chronic joint pain. The findings emphasize the necessity of immediate intervention to protect these high-risk groups.

Geological and Climatic Correlations

The correlation analysis between fluoride levels and geological features confirmed that groundwater in regions with fluoride-rich granitic and gneissic rocks exhibited significantly higher contamination. Climatic data analysis further revealed that low-rainfall areas were more susceptible to high fluoride concentrations due to limited natural dilution. Areas including Seeragadi, Veerapandi, Kondalampatti and Aatayampatti, which are well-defined by semi-arid circumstances, constantly displayed fluoride levels surpassing 4mg/L during the whole year. This condition highpoints the unescapable problem of fluoride contamination in drinking water in the Salem south region, predisposed by geological processes and climatical conditions. The outcomes of this study deliver a foundation for expressing

supportable approaches aimed at safeguarding safe drinking water and improving the health influences of fluorosis in at-risk populations.

Discussion

The outcomes of this study disclose a serious public health trial postured by extreme fluoride concentrations in drinking water springs in the Salem south region. Fluoride levels in 42% of the collected water samples exceeded 1.5 mg/L, with some zones documenting high concentrations. These outcomes coincide with previous findings in India, where geological developments and climatic situations have been acknowledged as key contributors to fluoride pollution (Shaji *et al.,* 2024). The elevated fluoride levels in water, particularly in areas such as Seeragadi, Veerapandi, Kondalampatti, and Aatayampatti, are strongly linked to the presence of fluoride in the primary rock strata, as evidenced by previous hydrogeological research (Sulaiman *et al.,* 2023).DF was experiential in 68% of children in high-fluoride areas and reliable with earlier studies conducted in fluoride-rich areas (Choubisa *et al.,* 2025; Yang *et al.,* 2026*).* The detected association between fluoride and DF occurrence ($r = 0.76$, $p < 0.01$) emphasizes the dose-dependent feature of fluoride's harmfulness (Das *et al., 2025*). Evolving research specifies the latent neurotoxic properties of fluoride, especially in children. The experiential connotation between high fluoride levels and tooth color change in this study is reliable with discoveries from a meta-analysis conducted (Taylor *et al.,* 2020). For each 1 mg/L upregulation in urine fluoride, a decline of 1.63 IQ points has been reported, increasing apprehensions about the wider implications of fluoride's, increasing apprehensions about the wider implications of fluoride harmfulness on children (Grandjean & Landrigan,2014). The universality of DF in school children further specifies noteworthy early-life acquaintance, demanding imperative public health interventions to guard this susceptible population. The spatial and periodic variability of fluoride concentrations detected in the present study emphasizes the complex interaction of normal and anthropogenic features in defining the level of contamination.Concentrated groundwater abstraction for agricultural drives, predominantly in semi-arid regions like Seeragadi, Veerapandi, Kondalampatti and Aatayampatti, has been acknowledged as a contributory feature to higher fluoride conditions. Excess extraction of groundwater lowers the water table, increasing the communication between groundwater and fluoride-holding rocks (Ghosh & Jha, 2024; Rehman *et al.,* 2026). Thus, concluding points insist on maintainable groundwater practices that include controlled withdrawal and renewed improvement to alleviate fluoride pollution.

Cost-effective defluorination approaches, like activated alumina and others, have been established as operative in reducing fluoride levels in groundwater and are licensed as feasible solutions in the Salem region (Ayoob & Gupta, 2006). Moreover, the performance of rainwater harvesting offers supportable approaches to decrease fluoride levels and pledge the attainability of good drinking water (de Sá *et al.,* 2024). Preceding interventions in comparable circumstances have established the efficiency of community-based methods in modifying fluoride acquaintance and highlighting health consequences (Prasad *et al.,* 2023). Furthermore, while the study is intensive on fluoride in drinking water, nutritional sources of fluoride, such as food, might subsidize the entire fluoride intake and permit further examination. Therefore, the problem of fluoride pollution in drinking water in the Salem South District is determined by environmental, climatological, and anthropogenic features. By joining geospatial examination and seasonal looks, this present finding offers a robust foundation for emerging evidence-based approaches to confirm good drinking water and progress the quality of life for pretentious communities.

Limitations

The present study is restricted only to the Salem South region, and water sample collection was done only in a few selected areas of the region. The increase in groundwater fluoride in the region has to be correlated with other influencing geographical conditions of the region.

Future Scope of the Study

A multicentric study involving different regions of Tamil Nadu analyzing the groundwater fluoride content and health issues resulting from this problem can be conducted in detail in the future. The long-term assessment of community-based defluorination techniques in fluoride-endemic areas is severely lacking in research. The majority of studies focus on dental fluorosis prevalence and fluoride monitoring, with little data on the long-term viability and efficacy of defluorination treatments. Additionally, there is still insufficient research on long-term health surveillance evaluating systemic, skeletal, and dental outcomes after fluoride reduction.

Conclusion

This research work highlights the extensive problem of fluoride pollution in drinking water in the Salem South region, with approximately half of the experimented water springs surpassing safe limits. By examining tooth observations and conducting seasonal monitoring, the study provides crucial insights into contamination flashpoints and their health impacts. These conclusions underline the imperative need for maintainable justification approaches and beleaguered public well-being interventions to ensure safe water.

Conflict of Interest

The authors declare that they have no competing interests.

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