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Original Research Article

Prevalence and severity of dental and skeletal fluorosis in a fluoride-endemic region of Karnataka, India

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ABSTRACT

Background: Fluoride contamination in groundwater poses a major public health concern in rural India, where long-term exposure leads to dental and skeletal fluorosis. This study aimed to assess the prevalence and severity of fluorosis in a fluoride-endemic region of Karnataka and to examine its association with demographic factors.
Methods: A cross-sectional study was conducted among 246 residents aged 1-90 years in fluoride-affected villages. Dental fluorosis was assessed using the Modified Dean's Index, while skeletal fluorosis was identified based on clinical symptoms such as back and joint pain, reduced mobility, and difficulty in bending. Groundwater fluoride levels were measured, and statistical analyses, including Chi-square (χ^2) tests, were performed to determine associations between variables.
Results: Overall, 80.5% of participants exhibited dental fluorosis, of which 30.08% were severe. Skeletal fluorosis was detected in 21.13% of individuals, predominantly among adults aged 41-60 years. A significant association was found between skeletal fluorosis and age ($p=0.000$), sex ($p<0.001$), and between dental and skeletal fluorosis ($p=0.002$). Groundwater fluoride concentrations ranged from 7.9 to 9.5 mg/L, exceeding the WHO permissible limit by more than six times.
Conclusions: The study highlights the dual burden of dental and skeletal fluorosis in the region and identifies age- and sex-related vulnerability. Effective community-based awareness, safe water supply interventions, and preventive health strategies are urgently required to mitigate fluoride toxicity and its health impacts in rural populations.

Keywords: Dean's index dental fluorosis, Fluorosis, Groundwater contamination, India, Public health, Skeletal fluorosis

INTRODUCTION

Fluoride is a naturally occurring element that, at optimal concentrations (0.5-1.5 mg/L), is beneficial for dental health, preventing caries and strengthening enamel.[1] However, chronic exposure to elevated fluoride levels, especially through drinking water, can lead to a spectrum of health problems collectively known as fluorosis, including dental, skeletal, and systemic effects.[2,3] Globally, over 200 million people in more than 30 countries are at risk of fluoride toxicity, with India ranking among the most affected due to extensive dependence on groundwater for domestic and agricultural use.[4-6]

Dental fluorosis manifests as hypo mineralization of enamel, resulting in discoloration, mottling, pitting, and in severe cases, enamel loss, negatively impacting aesthetics and psychosocial wellbeing.[7-9] Children are most vulnerable during tooth development, and early-life exposure has long-term consequences on oral health.[10,11]

Skeletal fluorosis, a more debilitating condition, arises from prolonged high fluoride intake and leads to joint stiffness, pain, restricted mobility, and skeletal deformities.[2,12,13] The condition not only compromises physical health but also limits productivity, thus affecting the socio-economic status of affected households and increasing the economic burden on rural communities.[14,15]

India's endemic fluorosis regions include parts of Karnataka, Andhra Pradesh, Rajasthan, Gujarat, Bihar, and Uttar Pradesh, with groundwater fluoride concentrations often exceeding WHO permissible limits.[3,5,16] Several studies in India have focused separately on dental or skeletal fluorosis, yet integrated assessments of both conditions, coupled with demographic analysis, remain limited.[11,17,18] Understanding these dual impacts is crucial, as the prevalence of dental fluorosis can serve as an early indicator of systemic fluoride toxicity and impending skeletal manifestations.[5,18,19]

Fluorosis not only poses a health challenge but also exerts considerable economic pressure on India. Treatment costs, productivity loss due to disability, and the burden on primary healthcare systems exacerbate rural poverty, highlighting the intersection between environmental toxicity and socio-economic development.[20,21,15] Furthermore, lack of awareness, reliance on untreated groundwater, and inadequate mitigation strategies contribute to the persistence of fluorosis in endemic zones.[22,23]

Given this background, community-level epidemiological assessments are imperative. Such studies provide actionable insights for preventive strategies, including safe water interventions, public health awareness programs, and routine screening of vulnerable populations.[24,16,19] The present study, conducted in a fluoride-endemic rural community of Karnataka, aims to bridge these knowledge gaps by assessing both dental and skeletal fluorosis prevalence, evaluating associations with demographic variables, and quantifying environmental fluoride exposure. By providing a comprehensive framework for epidemiological assessment, this study contributes to evidence-based public health policy formulation and long-term mitigation strategies applicable both regionally and globally.

METHODS

Study area

The present investigation was conducted in Guntral village, Devadurga Taluk, Raichur District, Karnataka, India, located at 16°12′45″ N latitude and 76°52′30″ E longitude. The region lies in a semi-arid climatic zone underlain by hard-rock aquifers composed of granitic and gneissic formations that are hydro geologically prone to elevated fluoride due to mineraldissolution.

According to the 2011 Census of India, Guntral village had about 2,000 residents, mainly dependent on bore well water for domestic use. Panchayat records (2021-2022) indicate a current population of roughly 2,300. Guntral forms part of northern Karnataka's fluoride-endemic belt, where prolonged consumption of high-fluoride groundwater has led to widespread dental and skeletal fluorosis. Baseline hydrogeological mapping by the Department of Geology, Kuvempu University confirmed groundwater fluoride concentrations between 7.9 mg/L and 9.5 mg/L, justifying selection of the site for epidemiological assessment.

Study period

The study was conducted from September 2020 to December 2022. Groundwater sampling and fluoride analysis were performed between September 2020 and August 2021, covering both pre- and post-monsoon seasons. The community health and fluorosis survey was conducted from January 2022 to December 2022.

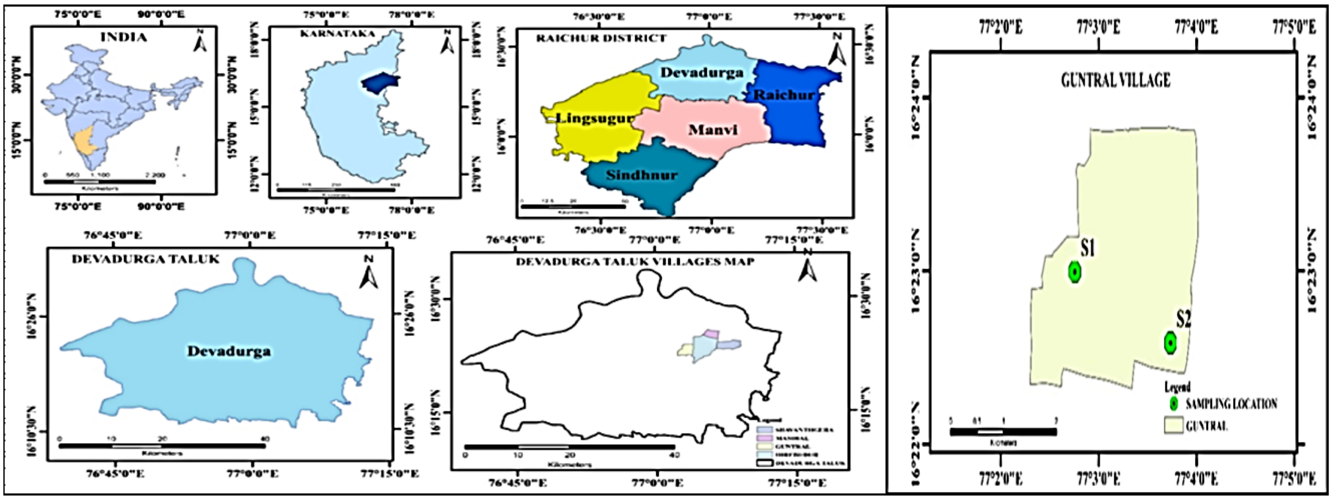

Figure 1: Study-area map showing Guntral village, Devadurga taluk, Raichur district, Karnataka, India.
The inset maps display the hierarchical location from India to guntral village. Sampling sites are marked with green dots.

Study design, sampling and data collection

A community-based cross-sectional study was carried out from January 2022 to December 2022 in Guntral village. The total population was approximately 1,240 (2011 Census), with agriculture as the major occupation. From this population, 246 individuals were selected through systematic household visits, ensuring proportional representation across age groups and sex. Inclusion criteria were: permanent residency in the village, consumption of local groundwater for ≥10 years, and willingness to participate. Exclusion criteria included temporary residents, individuals with chronic diseases unrelated to fluoride exposure, and infants below 1 year of age.

Data were collected using structured questionnaires and clinical examinations. Information on age, sex, occupation, and health complaints (joint or back pain, stiffness, limited mobility) was obtained by direct interview. Clinical assessments were performed in natural daylight at the household level, and written informed consent was obtained from all participants or their guardians.

Assessment of dental fluorosis

Dental fluorosis was evaluated using the Modified Dean's Index (WHO, 1997) the standard epidemiological tool for grading fluorosis severity. Each participant was examined under natural daylight by a calibrated investigator to minimize inter-observer variation. The index classifies fluorosis as: Normal (0): Translucent enamel, no signs of fluorosis; Questionable (0.5): Slight white flecks or aberrations; Very mild (1): Opaque white areas <25% of surface; Mild (2): Opaque areas ≤50% of surface; Moderate (3): Brown stains, pitting, aesthetic concern; Severe (4): Widespread enamel loss, hypoplasia, corrosion.

For each participant, the two most affected teeth were scored, and the highest score recorded as the individual grade. Findings were grouped into mild, moderate, and severe categories for statistical analysis.

Assessment of skeletal fluorosis

Skeletal fluorosis was diagnosed through clinical examination and self-reported symptoms collected during household surveys. Key diagnostic indicators included: Chronic pain in neck, back, or knee joints; Stiffness and restricted movement; Difficulty bending, squatting, or performing daily tasks; Observable spinal rigidity or abnormal posture.

Symptom reliability was cross-checked against occupational history and duration of groundwater use. Radiological testing was not performed due to limited resources; instead, a clinical diagnostic approach commonly applied in rural field studies was adopted. Cases were categorized as suspected (mild/moderate symptoms) or confirmed (severe disability and restricted mobility). This approach provided an accurate reflection of fluorosis burden under field conditions.

Groundwater sampling and fluoride analysis

To determine the fluoride concentration in groundwater, samples were collected from the two primary drinking sources of the village one bore well and one hand pump. Sampling was carried out from September 2020 to August 2021, covering both pre- and post-monsoon seasons to capture seasonal variations. Water was collected in pre-cleaned polyethylene bottles after flushing the sources for 5–10 minutes to remove stagnant water.

Fluoride concentrations were analyzed using a Fluoride Ion Meter (Thermo Scientific, Thermostat model) following the standard procedures recommended by the American Public Health Association (APHA, 2017).

The fluoride concentration in the collected samples ranged from 7.9 mg/L to 9.5 mg/L, which is far above the World Health Organization (WHO, 2011) permissible limit of 1.5 mg/L, indicating chronic exposure to excessive fluoride in the study area.

Statistical analysis

All analyses were performed using Microsoft Excel (Office 2016). Descriptive statistics summarized demographic data and fluorosis prevalence. Associations between categorical variables age, sex, dental fluorosis, skeletal fluorosis were examined using the Chi-square (χ^2) test. A p value <0.05 was considered statistically significant. Results are expressed as frequencies, percentages, and cross-tabulations.

RESULTS

Demographic profile of study participants

The demographic characteristics of the study participants provide essential context for understanding the extent of fluoride exposure across age and gender groups. A total of 246 individuals participated, including 120 males (48.8%) and 126 females (51.2%), aged 1-90 years. The population structure reflects the community's dependence on local groundwater sources for drinking and domestic purposes, making all age groups potentially susceptible to fluorosis.

Most participants (73.6%) were within the 10-50-year age range, representing the working-age population most vulnerable to fluoride exposure due to prolonged groundwater consumption.

Table 1: Age-wise distribution of study population.

Age group (years)	Individuals (N)	Percentage (%)
1-9	28	11.38
10-20	58	23.57
21-30	46	18.70
31-40	37	15.04
41-50	40	16.26
51-60	21	8.53
61-70	10	4.06
71-80	5	2.03
81-90	1	0.40
Total	246	100.00

Prevalence and severity of dental fluorosis

Dental fluorosis is the earliest visible indicator of fluoride toxicity. Using the modified dean's index, out of 246 examined individuals, 198 (80.5%) displayed signs of dental fluorosis. The distribution of severity levels is shown below.

Table 2: Distribution of dental fluorosis severity (Modified Dean's Index).

Fluorosis grade	Individuals (N)	Percentage (%)
Normal	48	19.51
Questionable	36	14.63
Very mild	17	6.91
Mild	42	17.07
Moderate	29	11.79
Severe	74	30.08
Total	246	100.00

More than 80% of the population exhibited dental fluorosis, and nearly one-third had severe manifestations, confirming chronic exposure to high-fluoride groundwater.

Prevalence and determinants of skeletal fluorosis

Skeletal fluorosis represents the advanced stage of chronic fluoride intoxication. Clinical assessments indicated that 52 participants (21.1%) showed symptoms of skeletal fluorosis, such as joint pain, stiffness, or restricted movement. Prevalence increased sharply with age and was higher among males.

Table 3: Prevalence of skeletal fluorosis in study participants.

Condition	Individuals (N)	Percentage (%)
Present	52	21.13
Absent	194	78.86
Total	246	100.00

Skeletal fluorosis affected approximately one-fifth of the population, predominantly adults aged above 40 years.

Association between age and skeletal fluorosis

A Chi-square test revealed a statistically significant association between age and skeletal fluorosis ($p<0.05$). Prevalence increased progressively with age, especially after 40 years (Table 4).

There is a statistically significant association between skeletal fluorosis and both age ($p<0.05$) and sex ($p<0.001$). Males and individuals above 40 years showed higher prevalence due to cumulative exposure over longer durations.

Relationship between dental and skeletal fluorosis

The coexistence of dental and skeletal fluorosis reflects the progression of chronic fluoride toxicity. Individuals with severe dental fluorosis frequently presented symptoms of skeletal involvement.

The statistically significant relationship ($p=0.002$) indicates that individuals with severe dental fluorosis were more likely to develop skeletal complications.

Table 4: Association of skeletal fluorosis with age and sex.

	Category	Skeletal fluorosis present, N (%)	Absent, N (%)	P value
Age in years	1-20	0 (0.0)	86 (100)	<0.001
	21-30	1 (2.2)	45 (97.8)	
	31-40	8 (21.6)	29 (78.4)	
	41-50	28 (70.0)	12 (30.0)	
	51-60	8 (38.1)	13 (61.9)	
	61-80	7 (46.7)	8 (53.3)	
	81-90	0 (0.0)	1 (100)	
Sex	Male	37 (30.8)	83 (69.2)	
	Female	15 (11.9)	111 (88.1)	

Table 5: Association between dental and skeletal fluorosis.

Dental fluorosis grade	Skeletal fluorosis present	Absent	Total	P value
Normal	8	40	48	0.002
Questionable	12	24	36	
Very mild	5	12	17	
Mild	4	38	42	
Moderate	8	21	29	
Severe	15	59	74	
Total	52	194	246	

DISCUSSION

The present study assessed the prevalence of dental and skeletal fluorosis among residents of Guntral village, Karnataka, a region with groundwater fluoride levels far exceeding the WHO permissible limit of 1.5 mg/L. The observed concentration range of 7.9-9.5 mg/L clearly indicates chronic fluoride exposure through drinking water. Similar concentrations have been reported in other parts of India where hard-rock aquifers dominate the hydro geological setting, confirming groundwater as the main route of fluoride intake in rural populations.[1-3]

A high prevalence of dental fluorosis (80.5%) observed in this study is consistent with findings from other fluoride-endemic regions of India.[4-6] The predominance of moderate and severe dental fluorosis suggests long-term exposure beginning in early childhood, as enamel defects typically develop during tooth formation. The results further emphasize the irreversible nature of dental fluorosis, which serves as a visual marker for community-level fluoride toxicity.

Skeletal fluorosis was detected in 21.13% of participants, primarily among adults aged 41-60 years, supporting previous evidence that chronic accumulation of fluoride in bones increases with age.[7-9] The significant association between age and skeletal fluorosis (p=0.000) underscores the cumulative effect of prolonged exposure. Similarly, the higher prevalence among males (p<0.001) may be attributed to greater physical activity, water consumption, and occupational exposure, as observed in earlier field studies from endemic Indian villages.[10-12]

A notable finding was the statistically significant relationship between dental and skeletal fluorosis (p = 0.002). Individuals with severe dental fluorosis were more likely to exhibit skeletal symptoms, indicating that visible dental changes can act as early indicators of systemic fluoride toxicity.[13] This correlation highlights the need for early screening programs in schools and rural health centers to prevent progression to irreversible skeletal deformities.

The results collectively point toward the urgent necessity of preventive interventions such as defluoridation of groundwater, public health education, and provision of alternative safe drinking water sources.[14,15] Awareness campaigns and periodic medical monitoring in affected areas can help mitigate health risks and reduce the social burden associated with fluorosis.

Although the study provides valuable epidemiological insights into fluoride exposure in a rural Indian setting, certain limitations must be acknowledged. Radiological and biochemical tests could not be performed due to resource constraints, and diagnosis of skeletal fluorosis relied on clinical symptoms and self-reports. The sample was confined to a single village, which may limit the generalizability of the findings. Future studies incorporating multi-village sampling, dietary fluoride assessment, and medical imaging would strengthen the understanding of fluoride-related health impacts and guide targeted interventions.

CONCLUSION

This study provides comprehensive evidence of fluoride-induced health effects in Guntral village, Karnataka, where groundwater fluoride levels (7.9-9.5 mg/L) greatly exceed permissible limits. The findings reveal a high prevalence of dental fluorosis (80.5%), with nearly one-third of cases in the severe category, and skeletal fluorosis affecting 21.13% of the population, primarily among adults above 40 years. Significant associations between skeletal fluorosis and both age (p=0.000) and sex (p<0.001), as well as between dental and skeletal fluorosis (p=0.002), highlight the cumulative and gender-influenced nature of fluoride toxicity. The results emphasize the urgent need for community-level interventions, including safe water supply, defluoridation technologies, and routine medical screening, particularly for vulnerable groups such as children and older adults. Strengthening public awareness and implementing preventive health measures are essential to reduce the burden of fluorosis and safeguard the health and productivity of rural populations in fluoride-endemic regions of India.

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