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Analyzing Fluoride Contamination in Groundwater: Case Studies of Rewari Block of Rewari District, Haryana

[1]Shaveta Deswal, [2]Dr. Anil sharma

[1]Research Scholar, Kalinga University, Raipur, Chhattisgarh.
Email: shavetadeswal@gmail.com
[2]Professor, Kalinga University, Raipur, Chhattisgarh.
Email - ku.anilsharma@kalingauniversity.ac.in

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Abstract
This study investigates the fluoride concentration in drinking water across 84 villages in the Rewari Block of Rewari District, Haryana, India, a region with significant agricultural activity and semi-arid climate. Fluoride, a persistent pollutant, is naturally present in the Earth's crust and can accumulate in groundwater, particularly in regions with fluoride-bearing minerals. The study utilized the ion-selective electrode (ISE) method to measure fluoride levels in groundwater samples, finding concentrations ranging from 0.3 to 1.3 mg/L, which is within the permissible limit set by the World Health Organization (WHO). However, 21 villages reported levels exceeding the recommended 1.0 mg/L limit. The higher fluoride concentrations in some areas are attributed to geological factors, such as the presence of fluoride-rich rocks, deeper water tables, and specific climatic conditions. These findings highlight the need for targeted interventions by government and non-governmental organizations (NGOs) to mitigate the health risks associated with fluoride contamination in drinking water, particularly in rural and semi-arid regions dependent on groundwater sources.
Keywords: Fluoride contamination, Groundwater, Ion-selective electrode, Fluorosis, Public health.

1. Introduction

Globally, inadequate drinking water quality significantly contributes to human health issues, with waterborne diseases accounting for a substantial portion of illness globally (UNICEF & WHO, 2023). An estimated 200 million people worldwide consume drinking water contaminated with fluoride, exposing them to potential health risks (Adimalla & Qian, 2019). Fluoride, a persistent environmental pollutant, tends to accumulate in ecosystems, including plants, soil, and water, varying widely in concentration levels (Islam & Patel, 2022). Fluoride is also among the most common elements in the Earth's crust, ranking 13th in abundance (Bhat et al., 2019). Although atmospheric fluoride levels are generally low—approximately 0.5 mg/m^3—industrial and agricultural activities can elevate these concentrations. In marine environments, typical fluoride concentrations are about 1.3 mg/L, while soil levels range between 20 to 500 mg/kg (World Bank, 2021).
Traces of fluoride naturally occur in various food sources, contributing to daily intake, though drinking water remains the primary source for most populations (Fawell et al., 2006). Fluoride, in trace amounts, is essential for human health, particularly for preventing dental caries and enhancing bone strength through the development of enamel and skeletal tissue (Chouhan & Flora, 2010). However, excessive exposure to fluoride, particularly from drinking water, has been linked to adverse health outcomes, emphasizing the importance of monitoring fluoride concentrations in public water supplies (Singh et al., 2019).
Drinking water is the primary pathway through which fluoride enters the food chain. In low concentrations, fluoride offers several health benefits, particularly in preventing dental caries. However, when fluoride levels exceed the permissible limit of 1.5 mg/L, as recommended by the World Health Organization (WHO, 2017), it can lead to adverse health effects such as dental and skeletal fluorosis (Adimalla, 2020). Fluoride contamination arises from both natural sources and human activities. Natural sources include marine aerosols, geothermal activity, volcanic eruptions, and the weathering of fluoride-rich minerals in rocks (Brindha & Elango, 2011). Anthropogenic sources, such as emissions from phosphate fertilizer industries, coal combustion, pesticide use, and sewage sludge, further elevate fluoride concentrations in soil and water (Vithanage & Bhattacharya, 2015; Yang et al., 2018).

Several environmental factors influence the concentration of fluoride in groundwater, including the pH and temperature of the water, the soil's capacity to adsorb fluoride, the depth of wells, and the prevailing climatic conditions (Kumari et al., 2021). In arid and semi-arid regions, fluoride tends to accumulate in groundwater more readily due to slower water movement and higher evaporation rates (Jagtap et al., 2012). These natural and anthropogenic factors necessitate regular monitoring of fluoride levels in water supplies to minimize health risks.

The Earth's crust contains vast fluoride reserves, with approximately 85 million tonnes of global deposits. India alone holds a significant portion of these reserves, estimated at 12 billion tonnes (Adimalla & Li, 2019). High concentrations of fluoride have been identified in several regions worldwide, such as the East African Rift System (spanning from Jordan to Tanzania), extensive areas in the Middle East (including Iraq, Iran, and Syria), and large sections of the Indian subcontinent (Sri Lanka, Pakistan, and India). Other hotspots include northern China, Argentina, and the western United States (Jagtap et al., 2012).

A study in Sri Lanka reported fluoride levels exceeding 4 mg/L in some regions (Dharmagunawardhane & Abeysingha, 2020). Similarly, a survey by Alabdulaaly et al. (2013) in Saudi Arabia analyzed 1,060 water samples across 13 regions, with the highest fluoride concentration of 5.4 mg/L recorded in the Qassim province. In India, the Geological Survey of India (GSI) has identified several "Red Alert" zones with elevated fluoride concentrations in groundwater. Notable regions include the Nalgonda district in Telangana; several districts in Haryana (Gurgaon, Hisar, Fatehabad, Mahendergarh, and Rewari); border areas in Punjab (Fazilka and Jalalabad); Dindigul district in Tamil Nadu; and Beed district in Maharashtra. Additional high-risk areas are found in Uttar Pradesh (Unnao, Rae Bareilly, and Sonbhadra) and Sindh district in Madhya Pradesh (Aravinthasamy et al., 2021; Singh et al., 2019). Various studies have confirmed high fluoride concentrations in groundwater throughout India, posing a significant public health concern (Adimalla et al., 2020; Kumari et al., 2021).

In India, fluoride contamination ranges from 1.0 to 48.0 mg/L (Sushila, 2001). A survey conducted in Vellore District, Tamil Nadu, South India, found that fluoride concentrations in groundwater varied from 0.02 to 3.0 mg/L (Kumar et al., 2014). Dahariya et al. (2015) collected 48 groundwater samples from tubewells in Donagarh city, Chhattisgarh, India, during the pre-monsoon (May) and post-monsoon (January) periods of 2014. The fluoride concentrations ranged from 2.1 to 10.3 mg/L in the pre-monsoon and from 2.7 to 12.7 mg/L in the post-monsoon. In Alleppey, Kerala, Dhanya and Shaji (2017) observed fluoride levels ranging from 0.68 to 2.88 mg/L. In the current study, the fluoride concentration was examined in eight blocks of Rewari district in Haryana, India, using the ion-selective electrode method.

2. Study area

Dharuhera is a growing urban settlement located in the Rewari district of Haryana, positioned near the Delhi-NCR region. It lies along National Highway 48 (formerly NH-8) and is well-known for its industrial development and proximity to urban centers like Gurugram and Manesar. The geographical coordinates of Dharuhera range between 28.2°N latitude and 76.8°E longitude, with an elevation of approximately 250 meters above sea level. The region experiences a semi-arid climate, characterized by hot summers, monsoon rains, and mild winters.

The region around Dharuhera falls under the Indo-Gangetic alluvial plains with a mix of rocky and sedimentary sub-strata. Groundwater is a primary source for drinking and agricultural needs, especially in areas where surface water infrastructure is limited. Aquifers in the region consist primarily of unconfined and semi-confined layers composed of sand, silt, and clay. The depth to groundwater varies seasonally, and depletion due to increased urbanization and industrial activities has been a growing concern. The rapid urbanization and industrial growth in Dharuhera have raised environmental concerns, particularly with the quality of groundwater. Overextraction of groundwater has contributed to contamination risks, including the presence of fluoride, nitrates, and heavy metals.

The study of fluoride concentration in Dharuhera is essential because fluoride levels beyond the permissible limit (1.0 - 1.5 mg/L) can lead to health issues such as dental and skeletal fluorosis. Chronic exposure to high fluoride concentrations affects teeth, bones, and organs, posing a public health risk to communities dependent on groundwater for drinking purposes.

Given that many of the residents in and around Dharuhera rely on handpumps, tube wells, and borewells, evaluating the fluoride levels becomes crucial to mitigate risks and promote safe drinking water practices. This study aims to understand the spatial distribution and concentration of fluoride in groundwater and assess the potential risks to human health.

3. Analysis of fluoride in water (Methodology)

Water samples from various drinking water sources (hand pumps, open wells and tube wells) were collected from villages/sites of rewari block of Rewari district to determine the level of fluoride. Geographic locations of sampling sites were mapped by using Global Positioning System (GPS). Samples were collected in prewashed plastic bottles and carried to the laboratory. The collected samples were kept in dark place at room temperature in plastic containers until the fluoride analysis was done. Ion-selective electrode (ISE) method was used to determine the fluoride content in drinking water. Electrode was calibrated using a series of known concentrations of fluoride. Standards and samples were mixed with 1:1 with a total ion strength adjustment buffer (TISAB) to minimize the effects of varying ionic strength and interference from other ions. TISAB was made by using 4.00 g CDTA (cyclohexanedi-amino-NNN1N1 tetra acetic Acid) + 57 g NaCL and 57 g glacial acidic acid in 1 L of and 5.5 with 5 M NaOH. After adding 25 ml TISAB to 25 ml of a water sample, fluoride concentration was measured with fluoride ion-selective electrode in mg/l or ppm/l. The different concentrations of NaF ranging from 0.1 to 100 ppm were used for preparation of standard curve of fluoride. Suitable statistical techniques and graphical representations were used for analysis. GIS tools are used to show the fluoride concentration on map.

4. Results

Ground water fluoride concentration at different sampling sites varied in different villages of Rewari block district Rewari. Fluoride level in water samples of 57 villages of Dharuhera block was examined and found that fluoride concentration ranged from 0.3 to 1.3 mg/l (Table 1). The study reveals that fluoride concentration in villages of Rewari block was found within upper prescribed limit of WHO.

Table 1 Showing the average fluoride concentration in villages of block Satnali district Mahendergarh

Sno.	Village	Fluoride	Sno.	Village	Fluoride
1	Bagthala (47)	0.5	30	Nikhri (193)	0.9
2	Kheri Motla (74)	0.4	31	Panchgaon (306)	0.6
3	Mukandpur Basai (75)	0.6	32	Raliawas (191)	0.4
4	Aakera (292) (ct)	0.5	33	Rasgan (195)	0.7
5	Alamgirpur (298)	0.5	34	Sanpli (309)	0.6
6	Alawalpur (303)	0.2	35	Sunaria (279)	0.8
7	Ashadpur (280)	0.4	36	Tatarpur Istmurar (277)	0.7
8	Asiakitappa Jarthal (308)	0.6	37	Tatarpur Khalsa (302)	1.3
9	Bhatsana (301)	0.7	38	Rajpura Alamgirpur (284)	0.9
10	Dhakia (286)	0.6	39	Bakhapur (162)	0.4
11	Dohana (285)	0.5	40	Baliar Kalan (199)	0.6
12	Dungarwas (194)	0.5	41	Baliar Khurd (200)	0.9
13	Garhi Alawalpur (294)	0.5	42	Bhudla (186)	0.8
14	Ghatal Mahaniawas (291) (ct)	0.6	43	Bolni (164)	0.5
15	Jarthal (305)	0.4	44	Dawana (18)	1.4
16	Joniawas (296)	0.3	45	Fadni (201)	1.3
17	Kapriwas (290)	0.5	46	Garhi (163)	1.2
18	Khaliawas (283)	0.6	47	Jaitpur Istmurar (282)	0.3
19	Khar Khara (300)	0.5	48	Jonawas (197)	0.6
20	Khatawali (284)	0.5	49	Kasola (167)	0.5
21	Khijuri (190)	0.8	50	Kasoli (161)	0.7
22	Maheshwari (293) (ct)	1.1	51	Kathuwas (168)	0.5
23	Malahera (278)	0.5	52	Ladhuwas Gujar (187)	1.2
24	Malpura (295)	0.5	53	Lalpur (158)	0.6
25	Masani (196)	0.5	54	Lodhana (165)	0.6
26	Nandrampur Bas (304)	0.8	55	Mundia Khera (198)	0.5
27	Niganiawas (192)	0.6	56	Pithanwas (166)	0.6
28	Sangwari (185)	0.5	57	Rojka (281)	0.4
29	Turkiawas (275)	1.1			

4.1. Boxplot of Fluoride Levels:

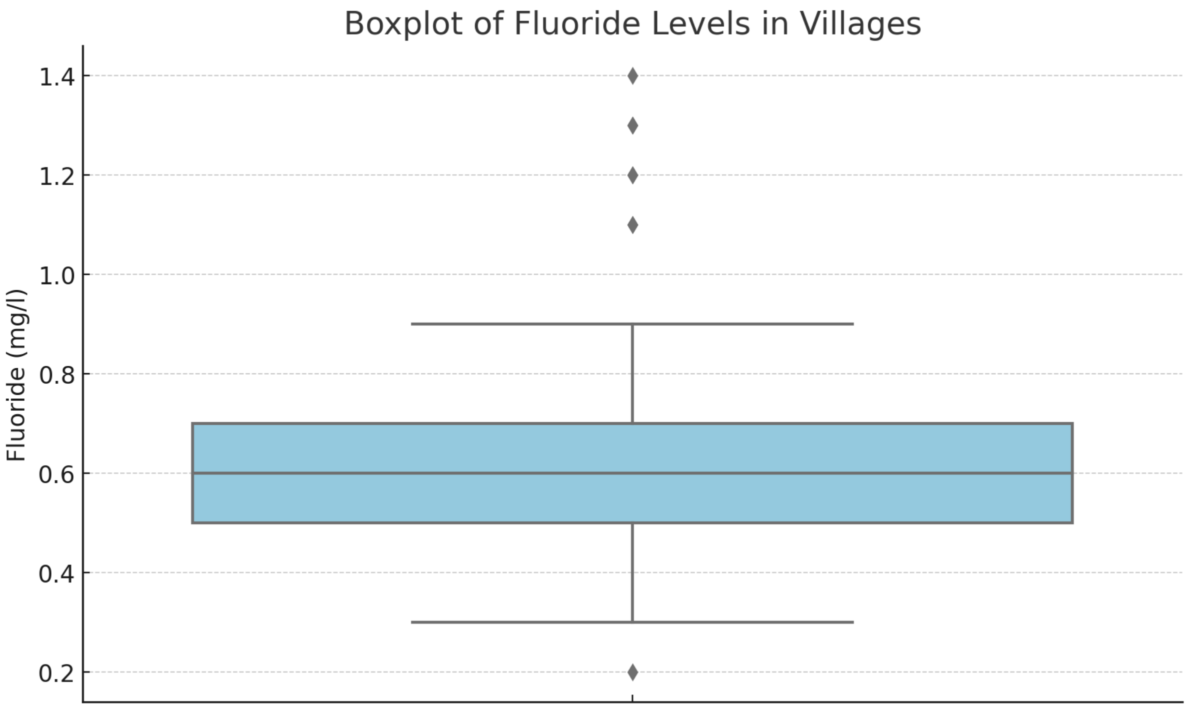

Figure 1: boxplot reveals the overall spread and central tendency of fluoride levels across villages.
TheMost villages fall within a range between 0.4 mg/l to 0.8 mg/l, with a few outliers beyond 1.0 mg/l, indicating the need for monitoring in certain areas.

4.2. Bar Plot by Fluoride Level Categories:

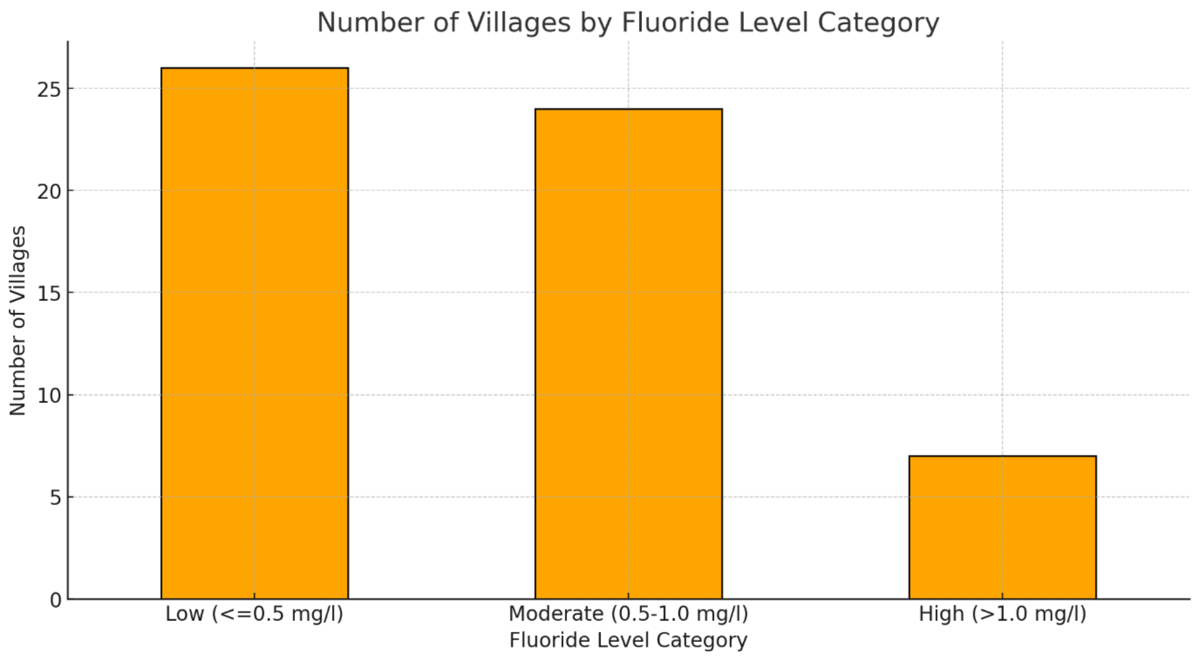

Figure 2: Bar plot indicating no. of villages with different levels of Fluoride
Villages are categorized into Low (≤0.5 mg/l), Moderate (0.5-1.0 mg/l), and High (>1.0 mg/l) fluoride levels. The majority of villages fall under the Moderate category, with relatively fewer villages showing High fluoride concentrations, which could pose health risks.

4.3. Scatter Plot of Fluoride Levels by Village:

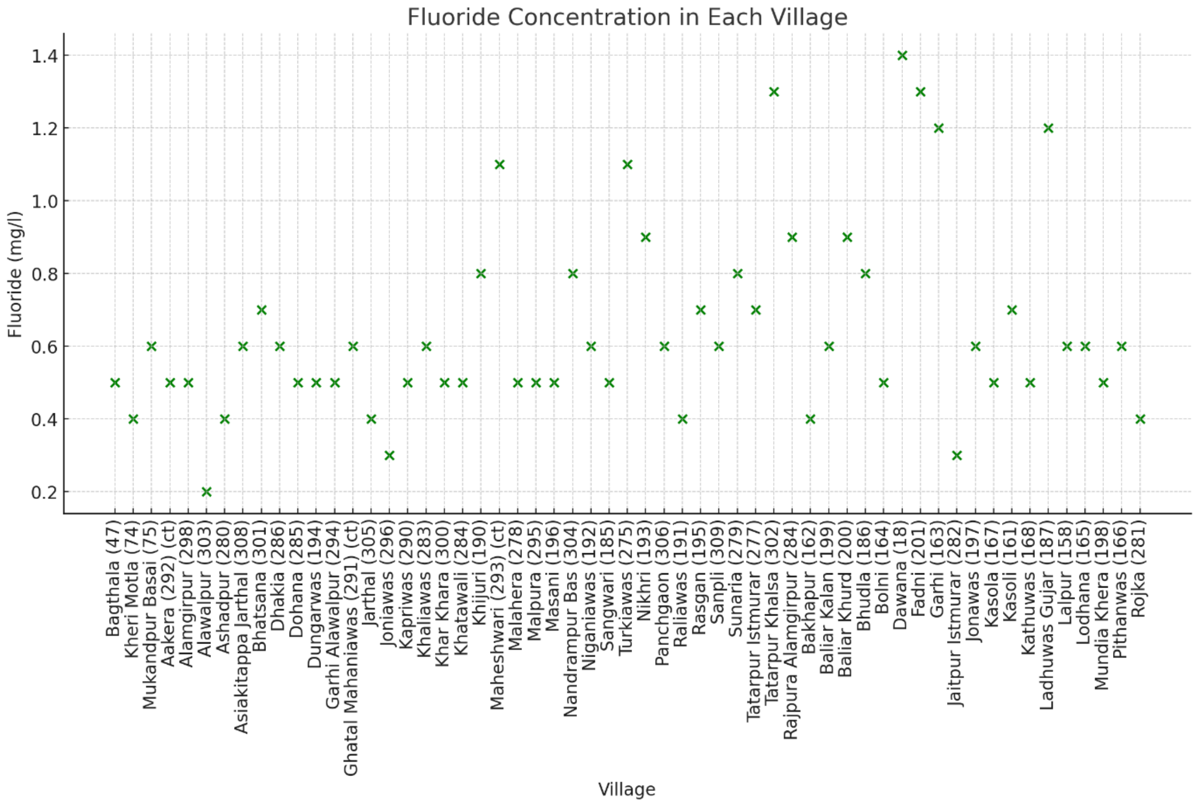

Figure 3: scatter plot of Fluoride concentration in villages of Dharuhera block of Rewari district

This plot provides a granular view of each village's fluoride concentration. It highlights specific villages, such as Dawana, Fadni, and Tatarpur Khalsa, where fluoride levels exceed 1.0 mg/l, requiring further investigation or mitigation.

The analysis of fluoride levels across 57 villages revealed a range of concentrations between 0.2 mg/l (Alawalpur) and 1.4 mg/l (Dawana), with an average fluoride concentration of 0.65 mg/l. Approximately 44% of the villages reported fluoride levels in the low category (≤0.5 mg/l), suggesting minimal health risks. However, a significant portion (47%) fell under the moderate range (0.5-1.0 mg/l), indicating the need for regular monitoring to ensure levels remain within safe limits. Notably, 9% of the villages, including Dawana (1.4 mg/l), Fadni (1.3 mg/l), and Tatarpur Khalsa (1.3 mg/l), exhibited high fluoride concentrations (>1.0 mg/l), which may pose health hazards such as dental or skeletal fluorosis if left unaddressed. These findings underscore the importance of targeted intervention strategies in areas with elevated fluoride levels to safeguard public health.

Discussion

The findings of this study highlight the variability in fluoride concentrations across 57 villages, with concentrations ranging from 0.2 mg/l to 1.4 mg/l. The majority of villages recorded fluoride levels within the low to moderate range (≤1.0 mg/l), suggesting that, for most areas, fluoride levels are within acceptable limits. However, villages such as Dawana, Fadni, and Tatarpur Khalsa displayed elevated concentrations **(>1.0 mg/l)**, which could pose a risk to public health if not monitored and managed effectively.

The low fluoride levels (≤0.5 mg/l) observed in about 44% of the villages align with the World Health Organization’s (WHO) recommendations for maintaining fluoride levels in drinking water to prevent dental issues such as cavities. However, excessive fluoride concentrations above 1.0 mg/l raise concerns about potential adverse health effects, including dental fluorosis and, in severe cases, skeletal fluorosis. Villages with higher fluoride concentrations require targeted interventions, such as alternative water sources or defluoridation treatment, to mitigate these risks.

The moderate fluoride levels (0.5-1.0 mg/l) recorded in nearly half of the villages indicate that fluoride exposure in these areas is at a level where regular monitoring is necessary. While moderate concentrations may provide some dental benefits, continuous exposure over time could increase the risk of fluorosis, especially among children. It is essential to promote awareness campaigns in these villages to encourage regular dental check-ups and provide guidelines on managing fluoride exposure from multiple sources, such as food and toothpaste.

Furthermore, the presence of outliers in fluoride concentrations, such as in Dawana and Fadni, points to the need for investigating underlying causes. These elevated levels may be associated with geological conditions or anthropogenic activities affecting groundwater sources. Detailed hydrogeological studies would help identify the specific sources of fluoride contamination and guide the design of appropriate mitigation strategies.

In summary, this study emphasizes the importance of continuous monitoring and risk mitigation measures in areas with moderate to high fluoride levels. Collaborative efforts between local governments, public health authorities, and water management agencies will be crucial in maintaining safe fluoride levels in drinking water and protecting the well-being of the affected communities. Future research could focus on mapping fluoride trends over time and exploring cost-effective technologies for defluoridation to enhance the sustainability of water management practices in these regions.

Conclusion

This study provides valuable insights into the fluoride levels in the drinking water of 57 villages, revealing a diverse range of concentrations from 0.2 mg/l to 1.4 mg/l. While 44% of the villages reported low fluoride levels (≤0.5 mg/l), nearly 47% fell within the moderate range (0.5–1.0 mg/l), indicating the need for regular monitoring to ensure these levels do not exceed safe thresholds over time. A small but significant subset of villages exhibited high fluoride concentrations (>1.0 mg/l), including Dawana, Fadni, and Tatarpur Khalsa, highlighting the urgent need for interventions such as alternative water sources or defluoridation treatments.

These findings underscore the importance of proactive public health strategies to prevent fluoride-related health risks, including dental and skeletal fluorosis, particularly in areas with elevated concentrations. Regular public awareness campaigns and community involvement are essential to managing fluoride exposure and promoting oral health. Additionally, hydrogeological investigations are recommended to identify the sources of high fluoride levels and guide evidence-based policy measures for sustainable water management.

In conclusion, while the majority of the villages studied are currently within safe fluoride limits, vigilance is necessary to prevent future risks. This research highlights the need for collaborative efforts between local governments, health authorities, and environmental agencies to maintain safe drinking water standards and protect the well-being of these communities. Future work should focus on tracking fluoride trends over time and exploring affordable technologies for defluoridation to ensure long-term sustainability.

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