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Evaluating Fluoride Hotspots and Suitability of Groundwater in Banswara District's Bagidora Tehsil

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ABSTRACT
Groundwater is the principal source of drinking water in rural Rajasthan, but elevated fluoride concentration has become a major environmental and public health concern. The present study evaluates fluoride hotspots and assesses the suitability of groundwater for drinking purposes in Bagidora Tehsil of Banswara District, Rajasthan. Groundwater samples were collected from 25 villages during pre-monsoon and post-monsoon seasons and analysed for fluoride and selected physico-chemical parameters, including pH, total dissolved solids (TDS), total hardness, alkalinity, and nitrate, using standard analytical procedures. Spatial distribution of fluoride was examined to identify high-risk zones. The results showed that fluoride concentration ranged from 0.4 to 4.8 mg/L, with several villages exceeding the permissible limit of 1.5 mg/L recommended by the World Health Organization (WHO). High fluoride concentrations were particularly associated with deeper tube wells and geological formations containing fluoride-bearing minerals such as fluorite and apatite. Water Quality Index (WQI) analysis indicated that approximately 36% of the samples were unsuitable for drinking purposes without treatment. The study highlights the need for regular monitoring, community awareness, and the implementation of fluoride mitigation techniques such as defluoridation units and alternative water sources in affected villages.
Keywords: Fluoride contamination, groundwater quality, Bagidora Tehsil, Banswara District, water quality index, fluorosis

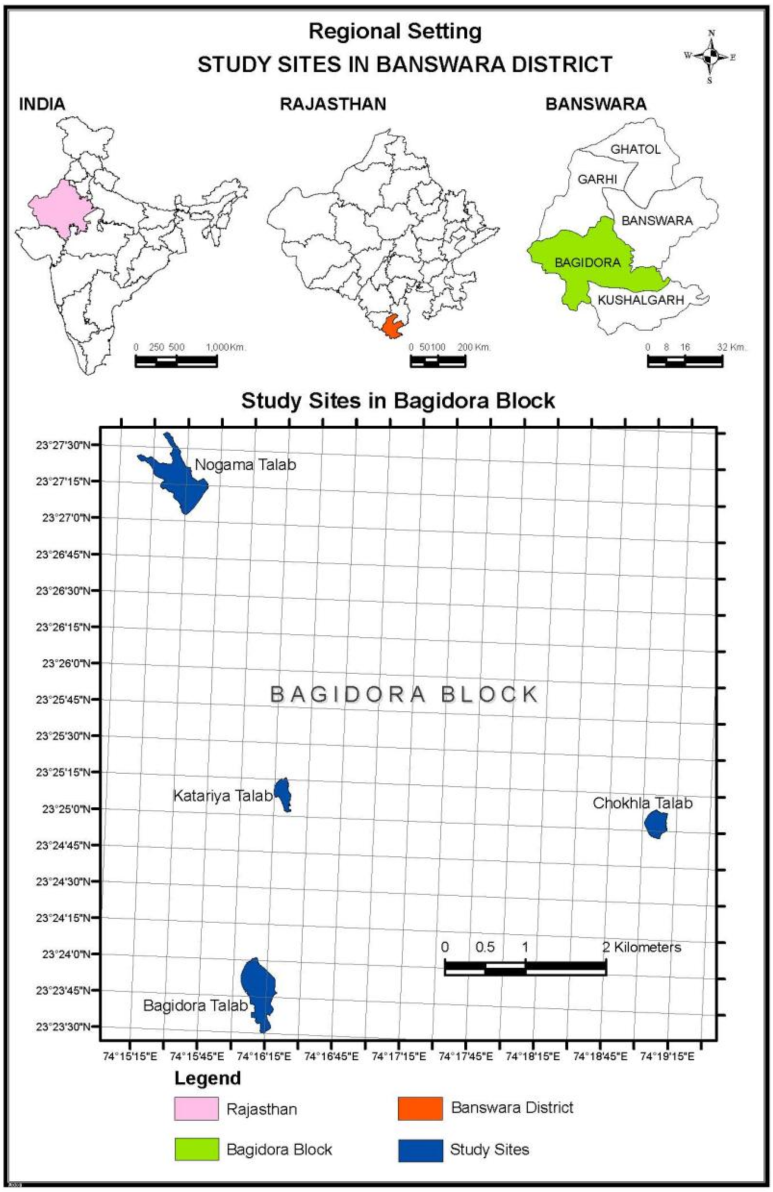
I. Introduction

Groundwater constitutes one of the most important sources of potable water in arid and semi-arid regions of India. In Rajasthan, dependence on groundwater is particularly high due to limited surface water availability and erratic rainfall patterns (Subba Rao, 2017; Jain, 2004). However, excessive concentrations of fluoride in groundwater have emerged as a serious environmental problem across several districts of the state (Smedley & Kinniburgh, 2002; Kumar et al., 2015). Naturally occurring fluoride originates mainly from the dissolution of fluoride-bearing minerals present in rocks and sediments, especially granites and gneisses (Edmunds & Smedley, 2005; Ayoob & Gupta, 2006). Fluoride in small amounts is beneficial for dental health, but prolonged consumption of water containing high fluoride concentrations may cause dental and skeletal fluorosis (Meenakshi & Maheshwari, 2006; Mishra & Bhattacharya, 2009). In Rajasthan, many districts, including Banswara, Udaipur, and Dungarpur, have reported high fluoride levels in groundwater sources used for drinking (Choubisa, 1997; Choubisa & Choubisa, 2016). Studies conducted in tribal villages of southern Rajasthan have reported fluoride concentrations reaching up to 10.8 mg/L, far exceeding permissible limits (Choubisa, 2014; Agrawal, 2023).

Bagidora Tehsil in Banswara District relies heavily on groundwater extracted from tube wells, hand pumps, and bore wells. The geological composition of the region includes fluoride-bearing rocks, which may contribute to elevated fluoride concentrations in groundwater (Smedley & Kinniburgh, 2002). The identification of fluoride hotspots and evaluation of groundwater suitability are therefore essential for ensuring safe drinking water supplies. The present study aims to evaluate fluoride distribution in groundwater of Bagidora Tehsil and assess the suitability of groundwater for drinking purposes using water quality parameters and indices (Singh et al., 2018; Rajankar et al., 2009).

Study Area

Bagidora Tehsil is located in Banswara District in southern Rajasthan, India. The region lies between approximately 23°15′–23°35′ N latitude and 74°10′–74°35′ E longitude. The area is predominantly inhabited by tribal communities and characterised by undulating terrain and seasonal rivers. The climate is the tropical monsoon type with three main seasons: summer (March–June), monsoon (July–September), and winter (October–February). The average annual rainfall ranges between 700 and 900 mm, mostly during the monsoon season. Groundwater occurs mainly in fractured and weathered rock formations. The main sources of drinking water include hand pumps, bore wells, and tube wells (Subba Rao, 2017).



II. Materials and Methods

Sampling Design

Groundwater samples were collected from 10 villages of Bagidora Tehsil during seasons. Samples were collected from hand pumps and tube wells using clean polyethylene bottles. The bottles were rinsed with distilled water and then with sample water before collection. Physico-chemical parameters were analysed using standard methods recommended by APHA and WHO (2017) guidelines for drinking water quality.

pH:

The pH of the water samples was measured using a calibrated digital pH meter. The electrode was immersed in the sample, and the stabilised reading was recorded at room temperature.

Total Dissolved Solids (TDS):

Total dissolved solids were determined by the gravimetric method by evaporating a known volume of filtered water sample to dryness in a pre-weighed dish. The residue obtained after drying at 105°C was weighed and expressed as mg/L.

Total Hardness:
Total hardness was estimated using the EDTA titrimetric method with Eriochrome Black T as an indicator at pH 10. The endpoint was indicated by a colour change from wine-red to blue and results were expressed as mg/L $CaCO_3$.

Alkalinity:
Alkalinity was determined by titrating a known volume of water sample with standard sulfuric acid using phenolphthalein and methyl orange indicators. The results were calculated and expressed as mg/L as $CaCO_3$.

Nitrate:
Nitrate concentration was measured using the spectrophotometric method. The intensity of the coloured complex formed was measured with a UV–visible spectrophotometer and expressed as mg/L.

Fluoride:
Fluoride was determined using the SPADNS colorimetric method. The reduction in colour intensity of the zirconium–SPADNS complex was measured spectrophotometrically at 570 nm and expressed as mg/L (Meenakshi & Maheshwari, 2006).

III. Results

Table 1 Physico-chemical characteristics of groundwater in Bagidora Tehsil

Parameter	Minimum	Maximum	Mean
pH	6.8	8.4	7.5
TDS (mg/L)	280	980	560
Total Hardness (mg/L)	110	460	280
Alkalinity (mg/L)	140	380	240
Nitrate (mg/L)	8	62	34
Fluoride (mg/L)	0.4	4.8	1.9

The physico-chemical characteristics of groundwater in Bagidora Tehsil show moderate variation among the analysed parameters (Table 1). The pH values ranged from 6.8 to 8.4 with a mean of 7.5, indicating that groundwater in the area is neutral to slightly alkaline. Total dissolved solids (TDS) varied between 280 mg/L and 980 mg/L, with an average of 560 mg/L, suggesting moderate mineralisation of groundwater. Total hardness ranged from 110 mg/L to 460 mg/L with a mean value of 280 mg/L, indicating moderately hard to hard water due to the presence of calcium and magnesium salts (Saxena & Ahmed, 2003; Tiwari & Singh, 2014). The alkalinity values varied from 140 mg/L to 380 mg/L, with a mean of 240 mg/L, reflecting the buffering capacity of groundwater mainly due to bicarbonates and carbonates. Nitrate concentration ranged between 8 mg/L and 62 mg/L, with an average of 34 mg/L, where higher values may be associated with agricultural runoff and fertiliser use (Gupta & Deshpande, 2004). Fluoride concentration varied from 0.4 mg/L to 4.8 mg/L with a mean value of 1.9 mg/L, indicating that in some locations fluoride levels exceed permissible limits and could pose potential health risks such as dental and skeletal fluorosis (Ayoob & Gupta, 2006; Smedley & Kinniburgh, 2002).

Table 2 Distribution of fluoride concentration in groundwater samples

Fluoride Range (mg/L)	Number of Samples	Percentage
<1.0	6	24%
1.0–1.5	10	40%
1.5–3.0	6	24%
>3.0	3	12%

The distribution of fluoride concentration in groundwater samples from Bagidora Tehsil shows considerable variation. Out of the total samples analysed, 6 samples (24%) recorded fluoride concentrations below 1.0 mg/L, which falls within the safe limit for drinking water. A larger proportion, 10 samples (40%), showed fluoride levels in the range of 1.0–1.5 mg/L, which is close to the permissible limit recommended for drinking purposes (WHO, 2017). Meanwhile, 6 samples (24%) exhibited fluoride concentrations between 1.5 and 3.0 mg/L, indicating levels above the desirable limit and posing a potential risk of dental fluorosis with prolonged consumption (Meenakshi & Maheshwari, 2006). Additionally, 3 samples (12%) recorded fluoride concentrations greater than 3.0 mg/L, which are considerably higher than the permissible limits and may lead to serious health problems such as skeletal fluorosis (Mishra & Bhattacharya, 2009; Choubisa & Choubisa, 2016).

Table 3 Water Quality Index classification

WQI Category	Samples	Percentage
Excellent	5	20%
Good	11	44%
Poor	6	24%
Unsuitable for drinking	3	12%

The Water Quality Index (WQI) classification of groundwater samples indicates varying levels of suitability for drinking purposes. Out of the total samples analysed, 5 samples (20%) fall under the excellent category, while 11 samples (44%) are classified as good quality. Additionally, 6 samples (24%) were categorised as poor, and 3 samples (12%) were found to be unsuitable for drinking, indicating that a portion of the groundwater in the study area requires treatment before consumption (Rajankar et al., 2009; Singh et al., 2018).

Table 4. Village-wise fluoride concentration in groundwater

S. No.	Village	Latitude	Longitude	Fluoride (mg/L)	WHO Status
1	Bagidora	23.53	74.44	1.2	Permissible
2	Kalinjara	23.49	74.47	2.8	Above limit
3	Sajjangarh	23.5	74.51	3.4	Above limit
4	Gamdi	23.46	74.43	0.9	Safe
5	Chhoti Sarvan	23.51	74.45	2.1	Above limit
6	Badi Sarvan	23.55	74.48	1.4	Permissible
7	Naugama	23.52	74.5	2.5	Above limit
8	Khodla	23.47	74.42	0.8	Safe
9	Jharkaniya	23.54	74.52	4.1	High
10	Dhanpura	23.58	74.49	3.2	High

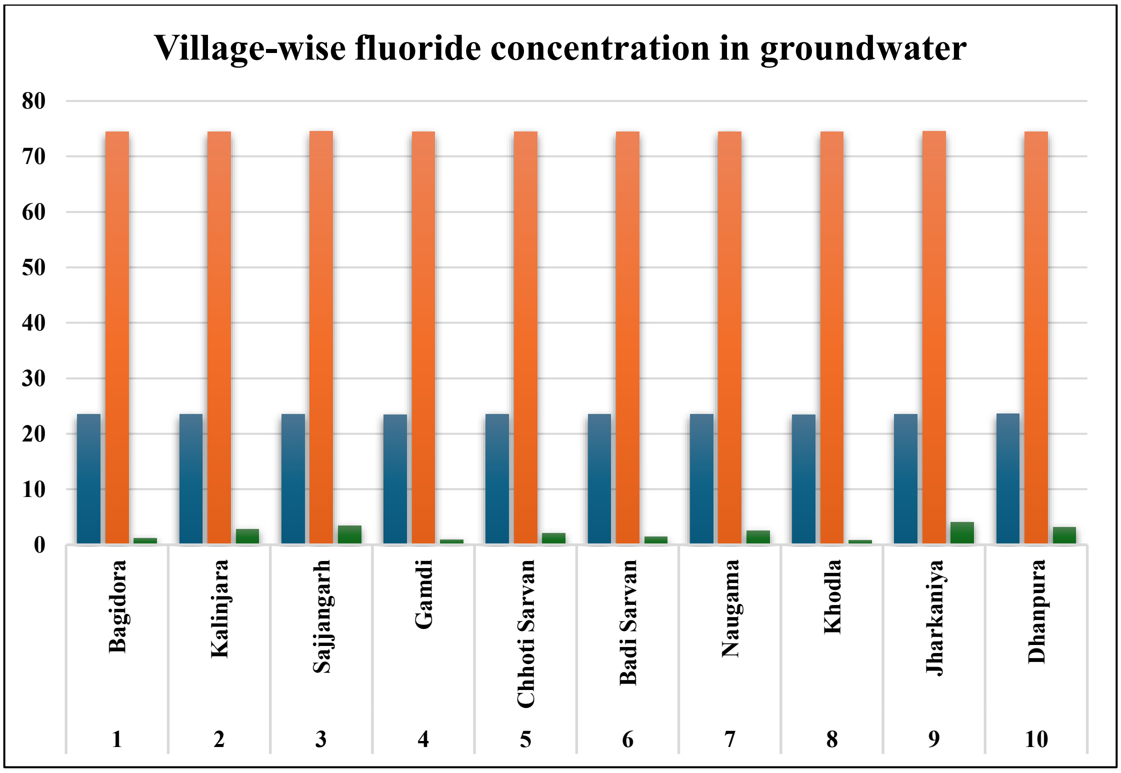


Fig. 1 – Village-wise fluoride concentration in groundwater

The village-wise analysis of fluoride (Table 4, Fig. 1) concentration in groundwater from Bagidora Tehsil shows considerable spatial variation. Fluoride levels ranged from 0.8 mg/L to 4.1 mg/L across the studied villages. The lowest concentrations were recorded in Khodla (0.8 mg/L) and Gamdi (0.9 mg/L), which fall within the safe limits recommended by the World Health Organization (WHO) for drinking water. Moderate fluoride concentrations within the permissible range were observed in Bagidora (1.2 mg/L) and Badi Sarvan (1.4 mg/L). However, several villages showed fluoride levels exceeding the recommended limit of 1.5 mg/L, including Kalinjara (2.8 mg/L), Sajjangarh (3.4 mg/L), Chhoti Sarvan (2.1 mg/L), and Naugama (2.5 mg/L). Particularly high fluoride concentrations were recorded in Jharkaniya (4.1 mg/L) and Dhanpura (3.2 mg/L), which fall under the high-risk category and may pose potential health hazards such as dental and skeletal fluorosis with prolonged consumption. The results indicate that certain villages of Bagidora Tehsil represent potential fluoride hotspots, highlighting the need for regular monitoring and appropriate mitigation measures to ensure a safe drinking water supply.

IV. Discussion

The groundwater quality of Bagidora Tehsil shows considerable variation in fluoride concentration. Approximately 36% of the sampled groundwater sources exceeded the permissible limit of 1.5 mg/L recommended by WHO (2017). High fluoride levels were primarily associated with deeper aquifers and areas underlain by fluoride-rich geological formations (Smedley & Kinniburgh, 2002; Edmunds & Smedley, 2005). Weathering and dissolution of minerals such as fluorite, apatite, and mica contribute significantly to fluoride enrichment in groundwater (Ayoob & Gupta, 2006). Low calcium concentration and alkaline conditions further enhance fluoride mobility in groundwater systems (Saxena & Ahmed, 2003).

Previous studies in Rajasthan have reported widespread fluoride contamination due to geological and hydrochemical factors (Choubisa, 1997; Choubisa & Choubisa, 2016). High fluoride concentrations have been reported from several districts, including Banswara, where groundwater serves as the primary drinking water source (Agrawal, 2023; Singh, 2021). Health impacts of high fluoride intake include dental fluorosis and skeletal fluorosis, which are common in many rural communities of Rajasthan relying on untreated groundwater sources (Meenakshi & Maheshwari, 2006; Mishra & Bhattacharya, 2009). The identification of fluoride hotspots in Bagidora Tehsil highlights the urgent need for mitigation measures such as:

- Installation of community defluoridation plants
- Rainwater harvesting

- Blending of high-fluoride water with low-fluoride sources
- Public awareness programmes

V. Conclusion

The present study evaluated the physico-chemical characteristics and fluoride distribution in groundwater of Bagidora Tehsil, Banswara District, Rajasthan. The analysis revealed that groundwater in the region is generally neutral to slightly alkaline with moderate mineralisation. Parameters such as total dissolved solids, hardness, alkalinity, and nitrate showed noticeable variation across different sampling locations. Among the studied parameters, fluoride concentration exhibited significant spatial variability, ranging from 0.4 mg/L to 4.8 mg/L with an average value of 1.9 mg/L. The results indicate that approximately 36% of groundwater samples exceeded the permissible limit of 1.5 mg/L recommended by the World Health Organization for drinking water. Elevated fluoride levels are primarily associated with the dissolution of fluoride-bearing minerals present in the geological formations of the region.

The Water Quality Index (WQI) assessment further indicated that while a considerable proportion of groundwater samples fall within the excellent and good categories, a significant percentage of samples were classified as poor or unsuitable for drinking purposes. The presence of high fluoride concentrations in certain areas poses potential health risks, particularly dental and skeletal fluorosis, which have been widely reported in several parts of Rajasthan. The findings highlight the importance of continuous monitoring of groundwater quality and identification of fluoride hotspots to ensure safe drinking water availability in rural communities.

To mitigate fluoride contamination in the study area, appropriate management strategies such as installation of community-based defluoridation units, rainwater harvesting, blending of high-fluoride groundwater with low-fluoride sources, and public awareness programmes should be implemented. Furthermore, the integration of hydrochemical analysis with geospatial techniques can assist in identifying vulnerable zones and planning sustainable groundwater management practices. The results of the present study provide useful baseline information for policymakers, water resource managers, and public health authorities in developing effective strategies to manage fluoride contamination in groundwater of Bagidora Tehsil and other similar regions of Rajasthan.

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