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FLUORIDE CONTAMINATION IN BHIWANI DISTRICT GROUNDWATER: SPATIAL DISTRIBUTION AND POTABILITY EVALUATION

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Abstract

The study examines the distribution patterns and suitability evaluation of fluorides occurring in Bhiwani District groundwater in Haryana. The researchers obtained 60 groundwater samples from tube wells hand pumps and bore wells through a stratified random sampling method across nine administrative blocks. Standard laboratory procedures were used to analyze physico-chemical parameters such as pH, Total Dissolved Solids (TDS) and Total Hardness (TH) and Calcium (Ca^{2+}) and Magnesium (Mg^{2+}) and Alkalinity and Fluoride. The analysis showed that pH levels and calcium concentrations were acceptable but TDS and hardness and magnesium and alkalinity exceeded their corresponding standards in various samples. Fluoride measurements in the studied water samples showed values from 1.1 to 2.1 mg/l while the WHO and BIS guideline value of 1.5 mg/l was exceeded by 44% of tested samples mainly found in Dadri-I, Dadri-II and Tosham blocks. The research data highlights the ongoing requirement for sustained monitoring programs alongside defluoridation strategy deployment to protect drinking water safety in the selected area.

Keywords: Fluoride contamination, Groundwater quality, Bhiwani District, Physico-chemical parameters, Spatial distribution, Potability Evaluation.

1. INTRODUCTION

The people in rural India mostly obtain their drinking water from groundwater resources especially in the arid and semi-arid regions of Bhiwani District Haryana. The communities in these areas strictly rely on groundwater accessed through tube wells hand pumps and bore wells because surface water remains scarce. Scientists now confirm that fluoride and other geogenic contaminants can be found in drinking water and high levels expose people to dental and skeletal fluorosis health risks. The long-lasting use of water containing fluoride raises critical public health risks because it causes permanent health problems. Therefore, fluorosis monitoring and control needs immediate attention. The geological strata contain fluoride-rich minerals that dissolve into groundwater thus causing fluoride presence. The dental benefits of fluoride occur when its concentration stays within 0.5–1.0 mg/l but levels above 1.5 mg/l set by the World Health Organization (WHO) and Bureau of Indian Standards (BIS) can result in negative health impacts. The amount of fluoride pollution in water exists differently throughout different geographic areas because of a combination of geological aquifer types and water source depths together with regional groundwater characteristics. Water quality surveillance programs at the national level need regional assessments to determine vulnerable areas which help start proper preventive measures.

The research determines the spatial fluoride patterns in Bhiwani District groundwater while assessing its suitability for human consumption based on standard water quality measurements. The research obtained water samples from every administrative block in the district to determine fluoride-affected zones and establish the suitability of drinking water resources. The obtained results will guide local authorities and policymakers to initiate targeted interventions which include the installation of defluoridation units and awareness campaigns along with alternative water sourcing in priority regions.

2. LITERATURE REVIEW

Deswal et al. (2020) conducted a detailed examination of fluoride concentration in groundwater was done across five southwestern districts of Haryana which included Bhiwani. The researchers obtained 362 water samples between pre-monsoon and post-monsoon seasons. The fluoride concentration measurements in the study area yielded results between 0.03–7.7 mg/L during pre-monsoon and 0.02–9.97 mg/L during post-monsoon periods yet exceeded the WHO recommended level of 1.5 mg/L in 126 pre-monsoon and 119 post-monsoon test samples. Geologic granite bedrock served as the main cause behind water contamination. Spatial distribution revealed that Bhiwani ranked among the districts most severely impacted by high fluoride levels. Alkaline soil in Jhajjar's regions increased fluoride release during both monsoon seasons.

Ali et al. (2018) stated that exceeded both WHO and BIS maximum limits, the Siwani block of Bhiwani district exhibited extraordinarily high fluoride content reaching 18.5 mg/L. The concentration of fluoride was enhanced through the combination of Ca^{2+} precipitation caused by evapotranspiration and alkaline conditions that allowed fluoride to be released from clay minerals. The inhabitants of these areas have no other water options and therefore drink water containing fluoride contamination. Testing revealed that groundwater from the area was not suitable for irrigation purposes because most of the samples showed poor Magnesium Hazard (MH) and poor results for SAR, Na% and Kelly's Ratio.

Gahlot et al. (2020) stated drinking water fluoride serves as a leading factor in total fluoride consumption during a day. Community members benefit from small fluoride amounts in their water since it strengthens their bones and teeth but acceptably high fluoride levels can trigger dental and skeletal fluorosis as well as kidney stones and thyroid disorders and lower child mental development. The geochemical behavior of fluoride, water alkalinity, and presence of fluorite influence its mobility in groundwater. The district of Bhiwani in Haryana contains the highest recorded fluoride concentration at 86 mg/L which makes it one of the worst affected areas of the state.

Malik et al. (2023) examined Haryana's groundwater quality because intensive agricultural and industrial operations have caused increasing water contamination. Groundwater overexploitation has resulted in quality degradation because multiple districts reveal excessive fluoride levels together with salt content and nitrates as well as heavy metals and elevated alkalinity. The findings show the dangerous impact of such pollution on health and propose better water quality management strategies along with advanced treatment solutions to maintain potable water supplies.

3. RESEARCH METHODOLOGY

3.1. Research Design

This research utilized a cross-sectional, field-based analytical study design to evaluate fluoride content in groundwater and determine water potability between various blocks. The research involved the quantitative analysis of fluoride and related physico-chemical parameters through standard laboratory methods.

3.2. Study Area

The research was done in the Bhiwani District of Haryana state, India. Since Bhiwani is a semi-arid area with poor surface water resources, groundwater is the major source for domestic and drinking purposes. Nine administrative blocks comprise the district of Bhiwani, which include Bhiwani, Dadri-I, Dadri-II, Loharu, Tosham, Badhra, Siwani, Kairu, and Bawani Khera.

3.3. Sampling Technique and Sample Size

Stratified random sampling was used to collect 60 hand pump, tube well, and bore well groundwater samples from all nine blocks of Bhiwani district. Sample size in each block was proportional to the population density along with the frequency of groundwater sources to ensure equal spatial representation in the study.

3.4. Sample Collection Procedure

Groundwater samples were drawn in pre-cleaned 1-litre polyethylene bottles. Each source was flushed before sampling for 2–3 minutes to yield fresh and representative water. The samples were tagged and shipped to the laboratory in ice-boxes for instantaneous analysis.

3.5. Analytical Techniques

Water samples were analyzed for the following parameters with standard procedures:

- **pH:** Estimated by Eutech pH Tutor.
- **TDS (Total Dissolved Solids):** Gravimetric technique.
- **Total Hardness (TH),** Ca^{2+}, Mg^{2+}: Analyzed by EDTA titrimetric technique.
- **Total Alkalinity (TA):** Calculated by titration with H_2SO_4.
- **Fluoride (F^-):** Estimated after dilution with TISAB buffer pH 5.2 with the Hanna pH meter (Model HI 3222-02).

Analytical grade chemicals were used in all the tests. Repetition was ensured in triplicate with an error of ±3%.

4. DATA ANALYSIS

4.1. Physico-Chemical Characteristics of Groundwater Samples

Groundwater was sampled at 60 sites distributed throughout Bhiwani District for important physico-chemical parameters such as pH, Total Dissolved Solids (TDS), Total Hardness (TH), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Alkalinity, and content of Fluoride. Summarized in Table 1 are these parameters.

Table 1: Range of Physico-Chemical Parameters in Groundwater Samples

Parameter	Minimum	Maximum	WHO Limit (mg/l)	BIS Limit (mg/l)	Remarks

pH	7.1	8.2	6.5–8.5	6.5–8.5	Within permissible limits
TDS (mg/l)	312	1445	1000	500–2000	Some samples exceed WHO limit
Total Hardness (mg/l)	120.1	588.4	300	300	Majority samples exceed limits
Calcium (Ca^{2+}, mg/l)	25	144	75	75	Within limits
Magnesium (Mg^{2+}, mg/l)	14	185	50	30	Significantly higher in most samples
Alkalinity (mg/l)	42	212	120	200	Exceeded in several samples
Fluoride (mg/l)	1.1	2.1	1.5	1.5	~44% of samples exceed permissible limit

Table 1's groundwater quality analysis shows acceptable pH levels in 60 Bhiwani District areas. TDS and total hardness exceed WHO and BIS guidelines in several testing points, indicating water quality decline. Multiple samples showed higher magnesium levels, although most calcium values were within safe ranges. Alkalinity levels above permissible limits may increase fluoride ion mobility in some areas. In roughly 44% of analyzed water, fluoride levels above guidelines increase water potability and health hazards.

4.2. Spatial Variation in Fluoride Concentration

Table 2: Fluoride Concentration Frequency in Groundwater Samples

Fluoride Range (mg/l)	**No. of Samples**	**Percentage (%)**
< 1.1	0	0%
1.1 – 1.5	34	56%
> 1.5	26	44%
Total	**60**	**100%**

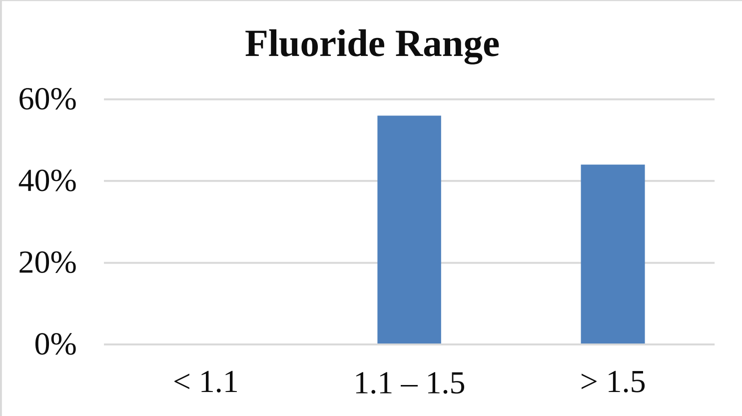

Figure 1: Fluoride Concentration Frequency in Groundwater Samples

The findings of Table 2 demonstrate that 44% of the tested Bhiwani District groundwater samples show fluoride concentrations beyond the WHO and BIS established maximum limit of 1.5 mg/l. The fluoride analysis showed all samples contained more than 1.1 mg/l but 56% of the examined samples existed within the recommended fluoride range of 1.1–1.5 mg/l. A serious fluoride contamination problem affects approximately 44% of the sampled locations introducing health threats for residents who rely on this groundwater to fulfill their domestic drinking needs.

4.3. Block-Wise Distribution of Fluoride Contamination

Table 3 shows average fluoride levels in Bhiwani District's nine administrative blocks.

Table 3: Block-wise Average Fluoride Concentration

Block	**No. of Samples**	**Average Fluoride (mg/l)**	**Above Permissible Limit (1.5 mg/l)**
Bhiwani	6	1.3	2
Dadri-I	7	1.8	5
Dadri-II	7	1.9	6
Loharu	6	1.4	2
Tosham	7	1.7	4
Badhra	7	1.3	2
Siwani	7	1.2	1
Kairu	6	1.1	0
BawaniKhera	7	1.2	1
Total	**60**	**1.44**	**26**

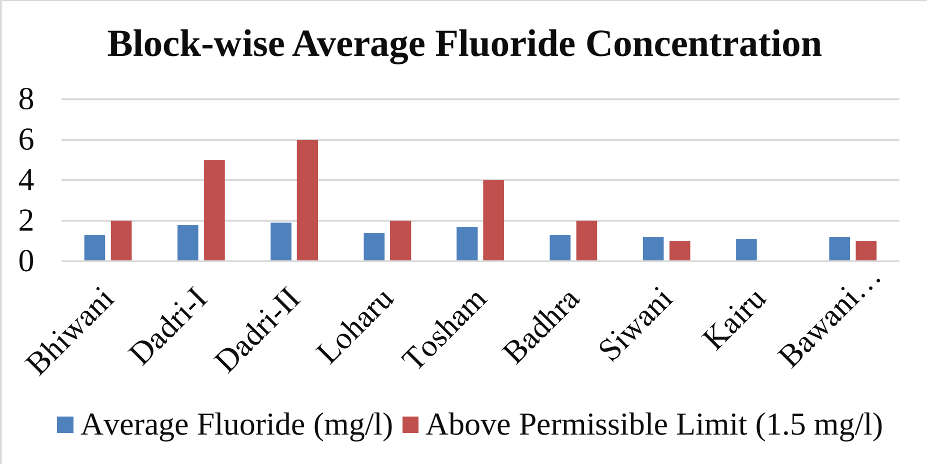

Figure 2: Block-wise Average Fluoride Concentration

The Dadri-II and Dadri-I water samples have the highest fluoride levels of 1.9 mg/l and 1.8 mg/l, respectively, exceeding the allowable 1.5 mg/l level with six and five samples. Tosham had 1.7 mg/l fluoride and four samples above the threshold. Kairu has the lowest average fluoride concentration of 1.1 mg/l, below the permissible amount. This data indicates fluoride-contaminated zones in the East and South, requiring specific preventative methods.

5. CONCLUSION

The research confirmed severe fluoride pollution of Bhiwani District's groundwater since 44% of tested water samples exceeded the WHO and BIS-established fluoride threshold at 1.5 mg/l. The combination of blocks Dadri-I and Dadri-II and Tosham demonstrates extraordinary fluoride susceptibility leading to health risks for the people who live there. The water quality received additional negative impact from total hardness and magnesium while alkalinity together with pH levels showed acceptable levels in water samples. The high-risk assessment calls for immediate sustainable groundwater management and regular water quality monitoring as well as the implementation of defluoridation techniques in these identified vulnerable areas for safeguarding the well-being of residents who rely on groundwater.

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