# Groundwater Quality Assessment and Health Risks from Fluoride in Jamui, Bihar

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## ABSTRACT

**This study aimed to determine the fluoride concentration in drinking water and assess its health risks by analyzing 12 physicochemical parameters, including fluoride, pH, EC, TDS, chloride, carbonate and bicarbonate (alkalinity), sulfate, nitrate, calcium, and magnesium hardness. Correlation analysis, WQI, and HRA were used to determine whether groundwater in the study area was suitable for drinking. Correlation analysis showed that fluoride was negatively correlated with EC (-0.649), $CO_3^{2-}$ (-0.855) and positively correlated with $Mg^{2+}$ (+0.559). All water samples exceeded the permissible fluoride limits according to BIS (IS 10500:2012). The WQI for all water samples was more than 100, indicating that the water was not suitable for drinking. Health risk assessment was also performed to determine the risks of non-carcinogenic diseases. The Hazard Index (HI) was determined as greater than 1. The HI ranged from 1.275 to 3.346 for adult men, 1.431 to 3.954 for adult women, and 1.986 to 5.4864 for children. Fluoride concentrations in drinking water pose a greater health risk to children than to adults. The fluoride level in drinking water is an essential parameter that must be monitored as a preventive measure against dental and skeletal fluorosis.**

***Keywords-groundwater; fluoride; correlation analysis; health risks***

## I. INTRODUCTION

A healthy lifestyle requires clean and safe water, as poor water quality causes health problems and social difficulties. In certain parts of the world, access to clean drinking water is difficult due to economic, environmental, and budgetary constraints [1, 2]. Many countries prioritize providing safe drinking water, but undeveloped and many developing countries cannot meet regulatory drinking water requirements [3-5]. Clean water services are not even accessible to 783 million people, according to the World Health Organization (WHO). More than half of humanity is expected to suffer from a drinking water crisis by 2025 [6]. Drinkable freshwater consumed is more often derived from groundwater than surface water due to the higher microbiological activity of the latter [7]. However, several geological processes increase groundwater contamination [8]. It is common for rural water sources to be contaminated by illegally discharged industrial, agricultural, and urban effluents. These contaminated water bodies harm humans and aquatic life [9, 10], and several efforts are being made to improve the quality of drinking water. The burden of waterborne diseases from consuming contaminated water is measurable and considerable [11], and it negatively affects society on an economic level [12].

Many studies have shown that fluoride, nitrate, and arsenic ions adversely affect living organisms [13]. The presence of excessive levels of fluoride in drinking water (>1mg/L) has raised concerns about public health and has been associated with several harmful health effects [4, 14-18]. When people drink excessive amounts of fluoride in water, they are more likely to have fluorosis, which can range from dental (1.5-4.0mg/L) to severe (>10mg/L), depending on the amount of $F^-$ consumed [5-6, 18-19]. Some areas have significant levels of $F^-$ in their groundwater due to natural sources present in those areas, making drinking water enriched with geogenic $F^-$ ions [20]. In sedimentary and igneous rocks, fluoride exists naturally in the minerals sellaite ($MgF_2$), cryolite ($Na_2AlF_6$), fluorite ($CaF_2$), and fluorapatite ($Ca_5(PO_4)_3F$) [21]. Few countries have established allowed limits for fluoride in drinking water in cooperation with the WHO to reduce overexposure to $F^-$. Fluorosis poses a significant risk to approximately 200 million people worldwide [22].

## II. STUDY AREA

The Bihar, Jamui district, located at latitude 24°55'N and longitude 86°13'E, was selected as the study area, while most of the district has hilly topography. Table I shows the geographical sampling locations.

TABLE I. LOCATIONS OF GEOGRAPHICAL SAMPLING

| Sampling locations | Latitude | Longitude |
|---|---|---|
| Harna (S1) | 86.41 | 24.7593 |
| Bishanpur (S2) | 86.316 | 24.984 |
| Nargango (S3) | 86.3544 | 24.7454 |
| Jokatia (S4) | 86.3544 | 24.7454 |
| Lalmatia (S5) | 86.3 | 24.9829 |
| Chandrasekhar Nagar (S6) | 86.3553 | 24.8916 |
| Primary School Chooljeevan Tola (S7) | 86.38 | 24.8 |
| Bhadwaria (S8) | 86.4624 | 24.7635 |
| Prakash Nagar (S9) | 86.388 | 24.8141 |
| Panch Pahari (S10) | 86.3362 | 24.7469 |
| Nabinagar (S11) | 86.1572 | 25.0292 |
| Malaypur (S12) | 86.2625 | 24.9717 |
| Majhwe (S13) | | |

## III. MATERIALS AND METHODS

### A. Sample Collection

The samples were collected in May-June 2022. A total of 13 groundwater samples were collected from 13 different sampling locations, as shown in Table I, according to the APHA (2005) guidelines. The water samples were collected after pumping for 10 to 15 minutes to eliminate stagnant water. Each water sample was collected in a 1L pre-cleaned plastic bottle and stored at 40°C in a dark box. The store box was carried to the laboratory for further analysis.

### B. Water Analysis

The APHA (2005) protocol was followed for all procedures. A portable water analyzer-371 (Systronics India Ltd.) was used to evaluate pH, TDS, and EC at the sampling locations. The argentometric method was used to determine chloride levels. The fluoride concentration was measured using SPADNS. The concentrations of nitrate and sulfate were determined using ultraviolet (UV) spectrophotometry. Calcium, magnesium, carbonate, and bicarbonate (alkalinity) concentrations were measured using titration.

### C. Water Quality Index (WQI) Calculation

The Water Quality Index (WQI) was established to evaluate groundwater suitability for drinking [32]. Table II shows the WQI ratings.

TABLE II. WATER QUALITY INDEX RATINGS

| Water Quality Index | Water Quality Status |
|---|---|
| 0-25 | Excellent |
| 26-50 | Good |
| 51-75 | Poor |
| 76-100 | Very Poor |
| >100 | Unsuitable for consumption |

### D. Calculating Health Risk Assessment (HRA)

The United States Environmental Protection Agency (US EPA) developed an approach to evaluate the risk to human health, which has since been extensively used [23-25]. The HRA is an essential reference for conserving and managing a groundwater environment [25-27]. Water and air are the primary sources of health risks for humans. This study focused on drinking water consumption as a primary route, using $F^-$ to compute HRA and noncarcinogenic risks by:

$$Intake_{oral} = \frac{C_W \times IR \times EF \times ED}{BW \times AT} \quad (1)$$

where $Intake_{oral}$ (mg/kg/day) is the average daily exposure dosage by groundwater consumption, $C_w$ is the amount of a specific contaminant (fluoride) present in groundwater (mg/L), *IR* is the intake rate for groundwater (*IR*=1.5L/day for adult men/women and 0.7L/day for children), *EF* is the exposure frequency (365days/year), *ED* is the exposure duration (ED=30 years for adults and 12 years for children) obtained from EPA, *BW* is the average body weight (55kg and 65kg for women and men, respectively, and 18.5kg for children) [29], and *AT* is the average exposure time (4380 days for children and 10950 days for adults). The Hazard Quotient (HQ) was applied to evaluate the fluoride risk as:

$$HQ_{oral} = \frac{Intake_{oral}}{RfD_{oral}} \quad (2)$$

where $HQ_{oral}$ and $RfD_{oral}$ are the hazard quotients and reference doses for noncarcinogenic pollutants through drinking water intake, and the oral reference doses of $F^-$ were obtained from the EPA as 0.04mg/kg/day. An $HQ_{oral}$ greater than 1 is considered a noncarcinogenic risk, while $HQ_{oral}$ equal to 1 is considered safe.

## IV. RESULTS AND DISCUSSION

### A. Physicochemical Analysis for Drinking Water

Table III shows the statistical analysis of the physicochemical parameters and a comparison with BIS (IS 1050:2012).

TABLE III. PHYSICOCHEMICAL PARAMETERS ANALYSED STATISTICALLY

| Variable | Unit | Minimum | Maximum | Mean | StdDev | BIS acceptable |
|---|---|---|---|---|---|---|
| $F^-$ | mg/L | 2.100 | 5.800 | 3.483 | 1.266 | 1 |
| pH | - | 7.590 | 8.570 | 8.167 | 0.290 | 6.5–8.5 |
| EC | µS/cm | 200.000 | 1850.000 | 723.077 | 460.351 | - |
| TDS | mg/L | 125.000 | 920.000 | 601.538 | 279.385 | 500 |
| $Ca^{2+}$ | mg/L | 0.180 | 60.000 | 20.960 | 20.853 | 75 |
| $Mg^{2+}$ | mg/L | 3.510 | 47.500 | 17.368 | 15.236 | 30 |
| $Cl^-$ | mg/L | 7.560 | 350.800 | 107.152 | 82.175 | 250 |
| $HCO_3^-$ | mg/L | 115.340 | 460.600 | 316.306 | 103.397 | - |
| $CO_3^{2-}$ | mg/L | 1.500 | 8.000 | 6.310 | 1.788 | - |
| $SO_4^{2-}$ | mg/L | 5.550 | 75.500 | 34.981 | 25.336 | 200 |
| $NO_3^-$ | mg/L | 7.550 | 36.850 | 16.390 | 7.949 | 45 |

### B. Analysis of Water Quality Index (WQI)

Figure 2 shows the WQI of the sampling locations. As can be seen, the water quality rating of all sampling locations was greater than 100, showing that the drinking water at the selected locations was not suitable for consumption. The fluoride was mainly responsible for the higher value of WQI.

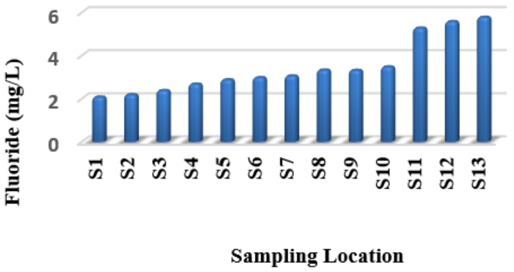


Fig. 1. Fluoride concentrations in the study area.

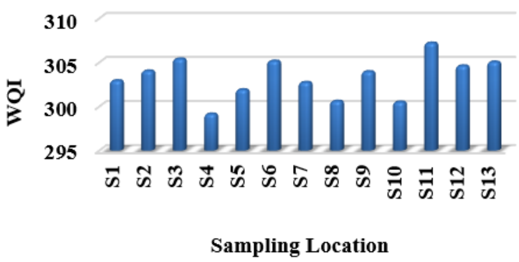


Fig. 2. WQI of the sampling locations

## C. Correlation Analysis

A correlation analysis measures and establishes the relationship between two factors [30]. A value less than 0.5 indicates a low correlation, 0.5 indicates a fair correlation, and greater than 0.5 indicates a very high correlation. Pearson's correlation coefficient reveals the essential connection between the unique variables obtained in the non-parametric form [31]. An inducement of zero demonstrates no relationship between the two variables, while a correlation coefficient of +1 or -1 indicates a strong correlation. Figure 3 shows the association between fluoride and the other water quality measures of the current study. Correlation analysis showed that fluoride was negatively and strongly correlated with $Ca^{2+}$ (-0.649) and $CO_3^{2-}$ (-0.855) and positively with $Mg^{2+}$ (0.559).

| Variables | pH | EC | TDS | $Ca^{2+}$ | $Mg^{2+}$ | $Cl^-$ | $HCO_3^-$ | $CO_3^{2-}$ | $SO_4^{2-}$ | $NO_3^-$ | $F^-$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | |
| EC | -0.145 | 1 | | | | | | | | | |
| TDS | -0.015 | -0.005 | 1 | | | | | | | | |
| $Ca^{2+}$ | -0.493 | 0.221 | -0.360 | 1 | | | | | | | |
| $Mg^{2+}$ | 0.030 | 0.209 | 0.269 | -0.419 | 1 | | | | | | |
| $Cl^-$ | -0.121 | 0.573 | -0.025 | -0.110 | 0.278 | 1 | | | | | |
| $HCO_3^-$ | 0.289 | 0.063 | -0.004 | -0.357 | 0.259 | 0.081 | 1 | | | | |
| $CO_3^{2-}$ | -0.220 | -0.180 | -0.070 | 0.465 | -0.177 | -0.287 | 0.196 | 1 | | | |
| $SO_4^{2-}$ | 0.117 | -0.025 | -0.066 | 0.024 | 0.413 | 0.247 | 0.362 | 0.384 | 1 | | |
| $NO_3^-$ | 0.270 | -0.115 | -0.474 | -0.175 | -0.181 | 0.276 | 0.227 | 0.314 | 0.132 | 1 | |
| $F^-$ | 0.201 | 0.225 | 0.308 | -0.649 | 0.559 | 0.470 | -0.015 | -0.855 | -0.060 | -0.245 | 1 |

Fig. 3. Fluoride correlation with the physicochemical parameters.

## D. Analysis of HRA

The population studied was classified into two groups:

- Children, aged between 2-16 years. Data from 50 children were collected.
- Adults, male or female, aged over 16 years. Data from 40 males and 25 females were collected.

Fluoride concentrations in drinking water pose a greater health risk to children than adults. The Hazard Index (HI) ranged from 1.275 to 3.346 for adult men, 1.431-3.954 for adult women, and 1.986-5.4864 for children. Table IV shows the noncarcinogenic risk for the sample in the study region.

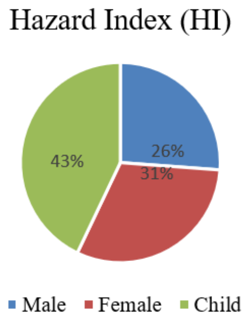


Fig. 4. Hazard index of males, females, and children.

TABLE IV. NONCARCINOGENIC RISK FOR MALES, FEMALES, AND CHILDREN IN THE STUDY REGION

| $C_W$ Fluoride | $Intake_{oral}$ (Male) | $Intake_{oral}$ (Female) | $Intake_{oral}$ (Child) | $HQ_{oral}$ (Male) | $HQ_{oral}$ (Female) | $HQ_{oral}$ (Child) |
|---|---|---|---|---|---|---|
| 2.1 | 0.121153846 | 0.057273 | 0.079459 | 3.028846154 | 1.431818182 | 1.986486486 |
| 2.21 | 0.051 | 0.060273 | 0.083622 | 1.275 | 1.506818182 | 2.090540541 |
| 2.4 | 0.055384615 | 0.065455 | 0.090811 | 1.384615385 | 1.636363636 | 2.27027027 |
| 2.7 | 0.062307692 | 0.073636 | 0.102162 | 1.557692308 | 1.840909091 | 2.554054054 |
| 2.9 | 0.066923077 | 0.079091 | 0.10973 | 1.673076923 | 1.977272727 | 2.743243243 |
| 3 | 0.069230769 | 0.081818 | 0.113514 | 1.730769231 | 2.045454545 | 2.837837838 |
| 3.08 | 0.071076923 | 0.084 | 0.116541 | 1.776923077 | 2.1 | 2.913513514 |
| 3.35 | 0.077307692 | 0.091364 | 0.126757 | 1.932692308 | 2.284090909 | 3.168918919 |
| 3.34 | 0.077076923 | 0.091091 | 0.126378 | 1.926923077 | 2.277272727 | 3.159459459 |
| 3.5 | 0.080769231 | 0.095455 | 0.132432 | 2.019230769 | 2.386363636 | 3.310810811 |
| 5.3 | 0.122307692 | 0.144545 | 0.200541 | 3.057692308 | 3.613636364 | 5.013513514 |
| 5.6 | 0.129230769 | 0.152727 | 0.211892 | 3.230769231 | 3.818181818 | 5.297297297 |
| 5.8 | 0.133846154 | 0.158182 | 0.219459 | **3.346153846** | **3.954545455** | **5.486486486** |

## V. CONCLUSION

This study investigated the fluoride contamination of groundwater samples in the Jamui district of Bihar, India, and examined the relationship between fluoride contamination and other water quality measures. The observed physicochemical data were compared with the Bureau of Indian Standards (BIS) limits, and it was found that fluoride exceeded the allowed limits. The fluoride was the leading cause of contamination in the selected area, responsible for a higher value of WQI. That indicates that drinking water at the selected locations is not suitable for consumption. Therefore, appropriate filtration units should be installed in hand pumps to remove the excess fluoride. Correlation analysis showed that fluoride is strongly negatively correlated with $Ca^{2+}$ (-0.649) and $CO_3^{2-}$ (-0.855) and positively with $Mg^{2+}$ (0.559). Regression analysis showed that fluoride has a decreasing trend with calcium and carbonate and an increasing trend with magnesium. Drinking water containing fluoride causes greater health risks in children than in adults, according to published risk assessments for human health. The range of possible values for the Hazard Index (HI) for adult men ranged from 1.275 to 3.346, for adult females from 1.431 to 3.954, and for children from 1.986 to 5.4864. In the study area, children are more susceptible to health risks than adults due to the highly polluted drinking water with high fluoride levels.

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