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A Proposed Method for the Quantification of Fluoride Contamination: Fluoride Pollution Index (FPI)

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Abstract

This study proposes a new index, Fluoride Pollution Index (FPI) for the identification and quantification of fluoride contamination as a function of its closely influencing factors (pH, Na/Ca ratio and HCO_3). The selection of these variables was in agreement with results obtained from their correlation analysis. The suggested method is explained on a case analysis from Thirupathur region in Tamil Nadu. Based on the relative concentration, weights were assigned to each parameter. FPI is calculated and classified as low (1-2), medium (2-3) and high (3-4) polluted. In the Thirupathur region, HPI values were ranged between 2.5 -3.75, shows that all the samples were medium (50%) to highly (50%) polluted with fluoride. Spatial distribution of FPI was showing a high value in the southern and northern ends of the study area. This method is taking in to account the relatively higher concentration of the influencing parameters that may be catalyzing the dissolution of the fluoride mineral in future. This method can be applied other parts of the world having similar hydrogeochemical conditions.

Keyword

Groundwater, Fluoride, Fluoride Pollution Index (FPI), Thirupathur

Introduction

Groundwater fluoride contamination is a growing concern in many part of the world. Several cases of F contamination were reported from various countries such as Argentina[1], India [2,3], Spain [4] and USA [5] and Iran [6]. In India, the permissible limit of fluoride in the drinking water is 1.2 mg/l [7]. However, an extended limit of 1.5 is allowed, which coincides with the [5] limit. A total of 14 Indian states has high fluoride (>1.5 mg/l) in groundwater. It is estimated that 65% of India drinking villages exposed to fluoride risk in the drinking water [8]. The major origin of fluoride in the groundwater can be attributed to the geological formations, such as the fluoride – rich minerals are fluorite, apatite, mica, amphiboles, clay and villiaumite. Availability and solubility of F minerals, pH, temperature, anion exchange capacity of aquifer materials, type of geological materials, residence time, porosity, structure, depth, groundwater age, concentration of carbonates and bicarbonates in water are the factors influencing groundwater fluoride contamination [9]. [10] reported that the Na- rich, Ca -poor water can enrich the groundwater fluoride through cation exchange. High pH values and the presence of HCO_3 may also elevate the F concentration in groundwater. However, there is no index available in the literature to quantify the fluoride hazard. Present study was carried out at Thirupathur Taluk in south India, where high concentration of Fluoride was already reported [11]. It is a semi arid; hard rock area predominantly consists of gneisses and charnockites. The climate is tropical with a mean range of temperature from 18.2–36.8°C. This area receives rainfall from both southwest and northeast monsoons with annual normal rainfall of 949.8 mm [12]. This paper reports new index, Fluoride Pollution Index (FPI) developed by considering the controlling factors of Fluoride contamination such as pH, HCO_3 and Na/Ca ratio, in order to critically evaluate and classify this hazard.

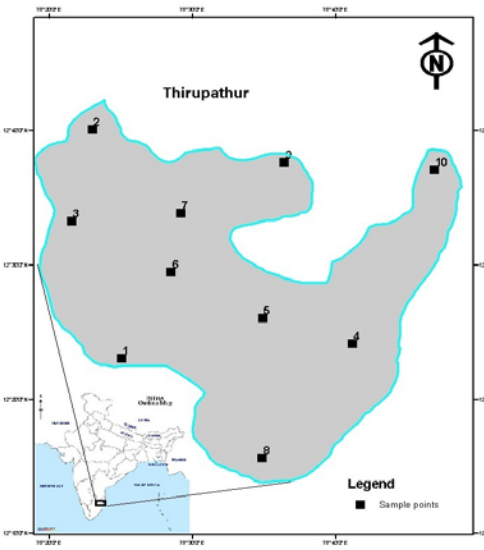

Fig. 1. Location map of the study area showing sample points

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1. Materials and Methods

Groundwater samples were collected from the Thirupathur Taluk and analysed for the parameters such as pH, HCO_3, Na and Ca using the standard methods recommended by [13]. HCO_3 and Ca were determined by titration. Na concentration was determined using flame photometer. Fluoride in the water samples was determined Using SPADNS method according to instruction of standard methods [14].

These data were used in the calculation of Fluoride Pollution Index (FPI). For the calculation, as initial step weights were assigned according to their corresponding concentration. The criteria adopted in assigning the weights for individual parameters are shown in Table 1. In the second step, FPI of the water samples were calculated using the equation 1.

$$\text{FPI} = (W_f + W_{HCO3} + W_{\frac{Na}{Ca}} + W_{pH})/N$$

Where W_F =weight of F, W_{HCO3} = weight of HCO_3, $W_{Na/Ca}$ = weight of Na/Ca W $_{pH}$ = weight of pH and N= total number of parameters. Based on the FPI range, water samples can be classified as Low (1-2), medium (2-3) and high (3-4), as shown in Table 2.

Tab.1. Criteria adopted for assigning weights to the water samples

F	Conc. (mg/L)	Weight
	<0.6	1
	.6-1.2	2
	1.2-1.5	3
	>1.5	4
HCO3	<100	1
	100-200	2
	200-300	3
	>300	4
Na/Ca	<1	1
	1 - 2	2
	2-3	3
	>3	4
pH	<7	1
	7-8	2
	8-9	3
	>9	4

Tab.2. Classification of water samples based on FPI

FPI range (mg/L)	Water Classification
1-2	Low
2-3	Medium
3-4	High

2. Results and Discussion

Based on the previous studies and literature review, four parameters (F, pH, Na/Ca and HCO_3 were selected for the calculation of Fluoride Pollution Index (FPI). However, a correlation analysis was conducted over these parameters for proving this argument. Fluoride showing a good positive correlation with pH (r=0.38), Na/Ca (r=0.47) and HCO_3 (r=0.66) respectively. This result supports the selection of these parameters for calculating the FPI. Correlation matrix for the groundwater samples were presented in Table 3.

Tab.3. Correlation matrix for the groundwater samples

	pH	Na/Ca	HCO_3	F
pH	1.00			
Na/Ca	0.76	1.00		
HCO_3	0.37	0.66	1.00	
F	0.38	0.47	0.66	1.00

Results of the water quality parameters used in the calculation of FPI and their corresponding weights are presented in Table 4. All the samples were alkaline in nature with a pH ranging from 8 - 8.7. Na/ Ca ratio was in the range of 1.27 -20.67, showing the dominance of Na. High concentration of the Na in the study area is largely controlled by two prominent processes such as silicate weathering and untreated effluents enriched in NaCl from the nearby Vaniyambadi tannery clusters. Enrichment from these both sources causes the dominance of Na over Ca in the groundwater. Carbonate rocks are absent in the study area, indicating that the origin of calcium is mainly due to the weathering of calcic-feldspars. Bicarbonate in the study area was relatively high with range of 191-595mg/l.

Tab.4. Concentration of hydrochemical parameters and their corresponding weights

S. No	pH	$W._{pH}$	Na/Ca	$W._{Na/Ca}$	HCO_3	$W._{HCO3}$	F	$W._F$
1	8.6	3	20.67	4.00	258	3	1.75	4
2	8.1	3	8.64	4.00	414	4	1.69	4
3	8.3	3	5.82	4.00	226	3	1.15	2
4	8.3	3	7.54	4.00	305	4	0.26	1
5	8.4	3	9.00	4.00	348	4	2.15	4
6	8.7	3	11.50	4.00	367	4	2.45	4
7	8.6	3	10.78	4.00	214	3	0.53	1
8	8.8	3	24.75	4.00	595	4	2.75	4
9	8.4	3	1.39	2.00	191	2	1.41	3
10	8	3	1.27	2.00	245	3	1.6	4

The major origin of Bicarbonate is the atmospheric precipitation and also as a byproduct during alteration of feldspar to clay. Elevated concentration of F above the permissible limit of 1.5 mg/l was shown by 60% of the samples. Natural geological formations as well as the anthropogenic activities are the major cause for the fluoride contamination in the study region [11].

FPI of the groundwater samples of in Thirupathur area is calculated by substituting the assigned weights from Table 4 to Eqn 1. Among the analysed samples, 50% of the samples were classified medium contaminated and the remaining 50% is categorized under the high contaminated class. FPI calculated for the individual groundwater samples are shown in Table 5. The results indicate that the groundwater quality of Thirupathur is contaminated with Fluoride. A slight variation from the fluoride concentration and the FPI is observed in few samples. The sample number 4 and 7 has a relatively less fluoride concentration of 0.26 and 0.53mg/l. Still they are categorized under the doubtful class. This can be explained by considering the other triggering factors on fluoride dissolution in the groundwater environment. High concentration of HCO_3 (305mg/l) in the sample number 4 and a higher Na/Ca ratio (10.78) may be catalyze the dissolution of fluoride minerals present in the hard rocks of the study area.

Tab.5. FPI of the groundwater samples in Thirupathur region, south India

S.NO	FPI	Water type
1	3.50	High
2	3.75	High
3	3.00	Medium
4	3.00	Medium
5	3.75	High
6	3.75	High
7	2.75	Medium
8	3.75	High
9	2.50	Medium
10	3.00	Medium

The spatial variation of FPI in the Thirupathur region is plotted in Fig. 2. The interpolated map suggest that majority of the area is under medium/or highly polluted with Fluoride. The highest concentrations were recorded for the southern-central regions and at the northern end of the Thirupathur.

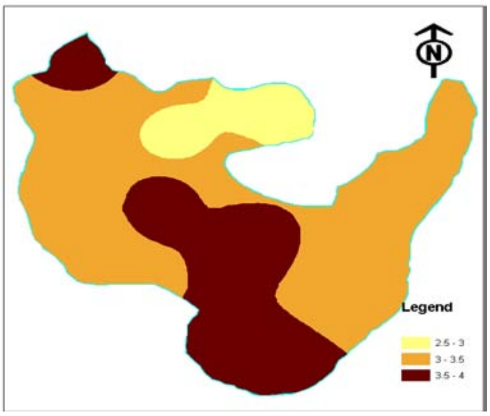

Fig.2. spatial variation of FPI in the Thirupathur region

3.Conclusions

Groundwater chemistry showed that the groundwater is alkaline in nature.

Selected four parameters the calculation of FPI, showed good correlation with fluoride; pH (r=0.38), Na/Ca (r=0.47) and HCO_3 (r=0.66) respectively.

Major hydrochemical processes controlling the occurrence of these parameters were identified as rock weathering and untreated effluent (for Na).

40% of the samples showed a high FPI values and the remaining samples showed medium FPI, suggesting high impact o human health

Highest FPI values were recorded at the southern-central regions. However, majority of the area is affected by fluoride incidence.

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