Analyzing the Relationship of Fluoride Contamination with Groundwater Temperatures in India

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Abstract: In this paper an attempt has been made to address fluoride contamination in groundwater of India from 2000-2020, along with its relationship with depth to water level and hots springs. Fluoride pollution has been widespread throughout India for decades. Because groundwater is India's primary supply of drinking water, fluoride pollution is a concern. The permissible limit of fluoride concentration by WHO is 0.6-1.5 mg/l while Bureau of Indian Standards (BIS) prescribes rather less vibrant range of fluoride 1-1.5 mg/l. Present study is review of fluoride concentration change in groundwater in past two decades of Indian states as well as validating the relation of fluoride concentrations with Depth to water level. With increasing depth to water level, the fluoride concentration in groundwater increases in 80% of the cases reviewed. Concentration of fluoride in Guwahati which is near the Brahmaputra River is higher (0.18 – 6.88 mg/l) than Nalbari (0.02 – 1.56 mg/l) which is away from Brahmaputra. There has been no significant change in the fluoride concentration in cases of Yavatamal & Guntur district during past two decades. In Nagaur district of Rajasthan fluoride concentration decreased from 8.5-28 mg/l in (2010) to 0.5-8.5 mg/l in (2013). In Unnao district fluoride concentration has increased from 1.45-3.75 mg/l in (2002) to 0.8-13.9 mg/l (2010). In case of Bihar, the areas of hard rock formations, the fluoride concentration were found to be higher while in the alluvial formations there were lesser cases of fluoride exceeding the required limit which is 1.5 mg/l. In Vellore district of Tamil Nadu fluoride concentration was found to be increasing within a period of 1 year from 0.2 – 3 mg/l in (2017) to 2.15 – 4.91 mg/l in (2018).
***Keywords*:** fluoride, hot spring, groundwater, depth to water level, fluorosis

1. Introduction

Fluoride is the first halogen of periodic table with atomic number 9 and atomic weight of 18.998 placed in 17th group in periodic table. Fluorine being most electronegative also means it is most reactive. Its abundance in universe makes it 24th most abundant element while in Earth's crust it is 13th most abundant element. Fluoride is vital for our health but within a certain limit. If that limit is breached, then same fluoride becomes nocuous for our health. Fluoride can reach our metabolic system via drinking water, beverages, toothpaste, phosphate fertilizers etc. Though in case of India groundwater is the culprit in majority of cases because groundwater is the only source of drinking water in India.

The permissible limit of fluoride concentration by WHO is 0.6-1.5 mg/l while Bureau of Indian Standards (BIS) prescribes rather less vibrant range of fluoride 1-1.5 mg/l. Fluorosis is a worldwide health problem. It is endemic in those areas where the fluoride content of drinking water is very high (Teotia and Teotia, 1984). More over dependence on ground water has grown over the past few decades and the quantity and quality of groundwater is also under threat especially in arid and semi-arid regions of the world (Ray et al. 2017; Li et al. 2017a; Adimalla and Venkatayogi 2018a; Adimalla and Li 2018). The F- bearing minerals such as fluorite, biotite and amphiboles are some of the geo-genic sources while industrial wastes, use of extensive fertilizers and brick kilns are examples of the anthropogenic sources (Ali et al., 2016). Detailed analysis of F− in groundwater have been widely studied (Amini et al., 2008; Battaleb-Looie et al., 2012; Li et al., 2014; Saha et al., 2016; Ali et al. 2016, 2018; Dehbandi et al., 2018; Podgorski et al., 2018) and various defluoridation methods have also been discussed elaborately (Mohapatra et al., 2009; Vithanage and Bhattacharya, 2015a and 2015b).

Given that groundwater is the primary source of fluoride in the supply (Amini et al., 2008), and groundwater is the primary developing-world water resource relied upon to meet SDG 6 (Xu et al., 2019), managing groundwater fluoride risk is a priority. Fluoride arises from groundwater dissolution of fluoride-rich lithologies, including clay minerals and micas (Battaleb-Looie et al., 2012), hornblende, amphibole and biotite in metamorphic Basement rocks (Bath, 1980; Mapoma et al., 2017), and (Basement) volcanic rocks, especially of alkaline composition (Ghiglieri et al., 2012). Manifestation of fluoride in deep-source springs or shallow groundwater may arise from discharge of hydrothermal groundwater from (Basement) rocks at depth, short-circuiting via fault pathways to surface (Edmunds and Smedley, 2013), recognising concentration of fluoride may occur in late stage hydrothermal fluids and pegmatitic mineralisation (Bath, 1980).

In 2017, a report was published suggesting that exposure to fluoride before birth could lead to poorer cognitive outcomes in the future. The researchers measured fluoride levels in 299 women during pregnancy and in their children between the ages of 6 and 12 years. They tested cognitive ability at the ages of 4 years and between 6 and 12 years. Higher levels of fluoride were associated with lower scores on IQ tests. In 2014, fluoride was documented as a neurotoxin that could be hazardous to child development, along with 10 other industrial chemicals, including lead, arsenic, toluene, and methylmercury.

2. Research methodology

The depth to water level data acquisition from Central Groundwater Board 2020 report shows the water table depth as an average of major depth findings for post monsoon. Chhattisgarh, Punjab, and Haryana showing depth to water level 20-40m while Rajasthan exceeding the 40 m depth mark and falls in water scarce state. High concentrations of fluoride in these four states mentioned above is likely because of deeper aquifer hence weaker bedrock containing fluorite and apatite minerals increasing fluoride contamination in the local groundwater.

Table 1. State-wise depth to water level

States of India	Mean Average Depth (m)
Andhra Pradesh	5-10
Arunachal Pradesh	0-2
Assam	2-5
Bihar	5-10
Chandigarh	20-40
Chhattisgarh	5-10
Delhi	10-20
Gujrat	10-20
Haryana	10-20
Himachal Pradesh	2-5
Jharkhand	5-10
Karnataka	5-10
Kerala	5-10
Madhya Pradesh	5-10
Maharashtra	10-20
Odisha	5-10
Punjab	20-40
Rajasthan	>40
Tamil Nadu	10-20
Telangana	20-40
Uttar Pradesh	5-10
Uttaranchal	10-20
West Bengal	5-10

Table 2. Fluoride concentration in Groundwater of India (at District Level)

S. No.	State	Districts	General range of Fluoride Concentration in Groundwater	References
1.	Andhra Pradesh	Guntur	0.3 to 1.80 mg/1	N. Subba Rao et al., (2003)
2.	Andhra Pradesh	Guntur	0.4 to 2.0 mg/l	N. Subba Rao (2005)
3.	Andhra Pradesh	Kurmapalli watershed	Up to 21.0 mg/l	Mondal et al., (2009)
4.	Andhra Pradesh	Visakhapatnam	0.6 -2.1 mg/l	Rao (2009)

S. No.	State	Districts	General range of Fluoride Concentration in Groundwater	References
5.	Andhra Pradesh	Wailapally Watershed	0.5 to 7.6 mg/l	Reddy et al., (2010a)
6.	Andhra Pradesh	Nalgonda	0.1 to 8.8 mg/l	Brindha et al., (2011)
7.	Andhra Pradesh	Talupula	0.78 to 6.10 mg/l	Arveti., et al (2011)
8.	Andhra Pradesh	Guntur	0.98 to 2.11 mg/l	B. Haribabu ., et al (2016)
9.	Andhra Pradesh	Prakasam	0.7 to 2.80 mg/l	Rao (2017)
10.	Andhra Pradesh	Markapur	0.4 to 5.8 mg/l	Sudarshan ., et al (2018)
11.	Andhra Pradesh	Kandivalasa river basin	0.36 to 2.34 mg/l	Prasad and Rao (2018)
12.	Assam	Guwahati	0.18 to 6.88 mg/l	Das et al., (2003)
13.	Assam	Nalbari	0.02 to 1.56 mg/l	Sharma ., et al (2012)
14.	Bihar	Indogangetic alluvial plain	0.08 to 5.8 mg/l	Kumar ., et al (2018)
15.	Chhatisgarh	Raigarh	1.0 to 8.8 mg/l	M.K. Beg ., et al (2008)
16.	Chhatisgarh	Bilaspur	0.73 to 3.02 mg/l	Manish K.R. Tiwari (2014)
17.	Chhatisgarh	Dongargaon Block	3.3 to 11.3 mg/l	Sahu ., et al (2017)
18.	Chhatisgarh	Dantewada	0.08 to 1.95 mg/l	Kumar ., et al (2018)
19.	Delhi	Southwest	0.0 to 1.9 mg/l	Acharya., et al (2018)
20.	Haryana	Jind	0.3 to 6.9 mg/l	Garg and Malik ., et al (2004)
15.	Chhatisgarh	Raigarh	1.0 to 8.8 mg/l	M.K. Beg ., et al (2008)
16.	Chhatisgarh	Bilaspur	0.73 to 3.02 mg/l	Manish K.R. Tiwari (2014)
17.	Chhatisgarh	Dongargaon Block	3.3 to 11.3 mg/l	Sahu ., et al (2017)
18.	Chhatisgarh	Dantewada	0.08 to 1.95 mg/l	Kumar ., et al (2018)
19.	Delhi	Southwest	0.0 to 1.9 mg/l	Acharya., et al (2018)
20.	Haryana	Jind	0.3 to 6.9 mg/l	Garg and Malik ., et al (2004)
21.	Haryana	Rohtak	0.034 to 2.09 mg/l.	Mukul Bishnoi (2005)
22.	Haryana	Hisar	0.03 to 15.6 mg/l	Ravinder and Garg (2006)
23.	Haryana	Hisar	0.1 to 9.2 mg/l	Ravinder and Garg (2007)
24.	Haryana	Gurugram	1.95 to 5.20 mg/l	Singh ., et al (2007)
25.	Haryana	Sirsa	0.1 to 1.9 mg/l	Mor ., et al (2009)
26.	Haryana	Bhiwani	0.14 to 86 mg/l	Garg ., et al (2009)
27.	Haryana	Jhajjar	0.10 to 4.30 mg/l	Mohammed Arif ., et al (2014)
28.	Haryana	Panipat	0.20 to 4.80 mg/l.	Bhupinder Singh and Anuradha (2019)
29.	Hyderabad	Koti	0.06 to 2.05 mg/l	Shailaja ., et al (2005)
30.	Karnataka	Banglore	1.47 to 6.12 mg/l	Shankar (2008)
31.	Karnataka	Kolar and Tumkur	0.36 to 3.34 mg/l	P. Mamatha ., et al (2010)
32.	Karnataka	Vijayapura	0.26 to 3.53 mg/l	Ugran (2017)
33.	Kerela	Palghat	0.2 to 5.75 mg/l	Shaji et al., (2007)
34.	Madhya Pradesh	Indore Zone	0 to 14.5 mg/l	Godfrey ., et al (2011)
35.	Madhya Pradesh	Dhar district	0.18 to 11.6 mg/l	Srikanth ., et al (2013)
36.	Madhya Pradesh	Chhatarpur	0 to 2.4 mg/l	Avtar ., et al (2013)
37.	Madhya Pradesh	Burhner watershed	0.04 to 14.6 mg/l	Prasad ., et al (2017)
38.	Madhya Pradesh	Balaghat, Chhindwara, Dhar, Jhabua, Mandla and Seoni	0.001 to 37.1 mg/l	Khare ., et al (2017)
39.	Madhya Pradesh	Singrauli	0.538 to 5.34 mg/l	Usham ., et al (2018)
40.	Maharashtra	Yavatmal	0.30 to 13.41 mg/l	Madhnure et al., (2007)
41.	Maharashtra	Yavatmal	0.06 to 12.71 mg/l	Pandith ., et al (2016)
42.	Maharshtra	Nanded	0.5 to 4.9 mg/l	Pandith ., et al (2017)
43.	Orissa	Bouden Block area	0 to 6.4 mg/l	Dey ., et al (2011)

S. No.	State	Districts	General range of Fluoride Concentration in Groundwater	References
44.	Punjab	Bhatindha	0 to 14.1 mg/l	Hundal and Khurana (2013)
45.	Punjab	Malwa belt	0.6 to 5.07	Ahada and Suthar (2018)
46.	Rajasthan	Ajmer	0.12 to 16.9 mg/l	C. Vikas ., et al (2004)
47.	Rajasthan	Jaipur	1.20 to 18 mg/l	Daisy Sabal and T.I. Khan (2008)
48.	Rajasthan	Hanumangarh	1.01 to 4.42 mg/l	Suthar ., et al (2008)
49.	Rajasthan	Sriganganagar & Hanumangarh	0.5 to 8.5 mg/l	Chaudhary ., et al (2010)
50.	Rajasthan	Bhilwara	0.2 to 13 mg/l	Hussain ., et al (2010)
51.	Rajasthan	Nagaur	8.5 to 28 mg/l	Rana ., et al (2010)
52.	Rajasthan	Pokhran	0.76 to 4.74 mg/l	Chander Kumar Singh ., et al (2010)
53.	Rajasthan	Hanumangarh	1.01 to 4.42 mg/l	Suthar ., et al (2011)
54.	Rajasthan	Sambhar lake	1.12 to 4.44 mg/l	Joshi and Seth (2011)
55.	Rajasthan	Nagaur	0.3 to 5.9 mg/l	Hussain ., et al (2012)
56.	Rajasthan	Didwana	0.4 to 6.6 mg/l	Arif ., et al (2012)
57.	Rajasthan	Tonk	0.3 to 9.8 mg/l	K.S. Meena ., et al (2012)
58.	Rajasthan	Nagaur	0.5 to 8.5 mg/l	Arif ., et al (2013)
59.	Rajasthan	Jaisalmer	0.08 to 6.6 mg/l	Singh and Mukherjee (2015)
60.	Tamil Nadu	Tirunelveli	0.73 to 3.02 mg/l	G. Alagumuthu and M. Ranjan (2008)
61.	Tamil Nadu	Ottapidiram	0.936 to 4.34 mg/l	Veeraputhiran ., et al (2010)
62.	Tamil Nadu	Erode	0.5 and 8.2 mg/l	Karthikeyan et al., (2010)
63.	Tamil Nadu	Chithar River Basin	0.17 to 1.3 mg/l	Subramani ., (2010)
64.	Tamil Nadu	Thirumanimuttar	0.03 to 4.2 mg/l	Vasanthavigar ., et al (2010)
65.	Tamil Nadu	Palar River, Kancheepuram	1.12 to 3.24 mg/l	Dar ., et al (2011)
66.	Tamil Nadu	Mettur Taluk, Salem district	0.1 to 4.0 mg/l	Srinivasamoorthy ., (2012)
67.	Tamil Nadu	Krishnagiri	1 to 3 mg/l	S. Manikandan e., et al (2012)
68.	Tamil Nadu	Theothukudi	0 to 3.3 mg/l	Singaraja ., et al (2013)
69.	Tamil Nadu	Rananathapuram	BDL to 2.96 mg/l	Sivasankar ., et al (2013)
70.	Tamil Nadu	Kanchipuram	0.05 to 1.04 mg/l	Pradeep kumar & SriPrakash (2013)
71.	Tamil Nadu	Cauveri River Delta	BDL to 1.57 mg/l	Vetrimurugan & Elango (2015)
72.	Tamil Nadu	Salem	0.12 to 1.66 mg/l	Arulbalaji & Gurugananam (2017)
73.	Tamil Nadu	Vellore	0.2 to 3 mg/l	Kumar ., et al (2017)
74.	Tamil Nadu	Vellore	2.15 to 4.91 mg/l	Sharmila ., et al (2018)
75.	Telangana	Siddipet	0.2 to 2.2 mg/l	Narsimha ., et al (2015)
76.	Telangana	Karimnagar	1.0 to 2.0 mg/l	B. Ramesh ., et al (2016)
77.	Telangana	Siddipet	0.4 to 2.2 mg/l	Narsimha (2018)
78.	Telangana	Medak (semiarid)	0.2 to 7.4 mg/l	Narsimha & Sudarshan (2018)
79.	Telangana	Nirmal	0.06 to 4.33 mg/l	Narsimha & Sudarshan (2018)
80.	Telangana	Medak	0.1 to 2.6 mg/l	Rajitha ., et al (2018)
81.	Uttar Pradesh	Unnao	1.45 to 3.75 mg/l	Rajendra (2002)
82.	Uttar Pradesh	Mathura	0.1 to 2.5 mg/l	Misra & Mishra (2007)
83.	Uttar Pradesh	Kanpur	0.14 to 5.34 mg/l	Sankararamakrishnan ., et al (2008)
84.	Uttar Pradesh	Unnao	0.8 to 13.9 mg/l	Jha ., et al (2010)
85.	Uttar Pradesh	Banda	0.32 to 3.5 mg/l	Surendra Singh (2016)
86.	Uttar Pradesh	Pratapgarh	0.41 to 3.59 mg/l	Tiwari ., et al (2017)
87.	Uttarakhand	Nainital	0.01 to 0.66 mg/l	Jha ., et al (2010)
69.	Tamil Nadu	Rananathapuram	BDL to 2.96 mg/l	Sivasankar ., et al (2013)
70.	Tamil Nadu	Kanchipuram	0.05 to 1.04 mg/l	Pradeep kumar & SriPrakash (2013)

S. No.	State	Districts	General range of Fluoride Concentration in Groundwater	References
71.	Tamil Nadu	Cauveri River Delta	BDL to 1.57 mg/l	Vetrimurugan & Elango (2015)
72.	Tamil Nadu	Salem	0.12 to 1.66 mg/l	Arulbalaji & Guruganamam (2017)
73.	Tamil Nadu	Vellore	0.2 to 3 mg/l	Kumar ., et al (2017)
74.	Tamil Nadu	Vellore	2.15 to 4.91 mg/l	Sharmila ., et al (2018)
75.	Telangana	Siddipet	0.2 to 2.2 mg/l	Narsimha ., et al (2015)
76.	Telangana	Karimnagar	1.0 to 2.0 mg/l	B. Ramesh ., et al (2016)
77.	Telangana	Siddipet	0.4 to 2.2 mg/l	Narsimha (2018)
78.	Telangana	Medak (semiarid)	0.2 to 7.4 mg/l	Narsimha & Sudarshan (2018)
79.	Telangana	Nirmal	0.06 to 4.33 mg/l	Narsimha & Sudarshan (2018)
80.	Telangana	Medak	0.1 to 2.6 mg/l	Rajitha ., et al (2018)
81.	Uttar Pradesh	Unnao	1.45 to 3.75 mg/l	Rajendra (2002)
82.	Uttar Pradesh	Mathura	0.1 to 2.5 mg/l	Misra & Mishra (2007)
83.	Uttar Pradesh	Kanpur	0.14 to 5.34 mg/l	Sankararamakrishnan ., et al (2008)
84.	Uttar Pradesh	Unnao	0.8 to 13.9 mg/l	Jha ., et al (2010)
85.	Uttar Pradesh	Banda	0.32 to 3.5 mg/l	Surendra Singh (2016)
86.	Uttar Pradesh	Pratapgarh	0.41 to 3.59 mg/l	Tiwari ., et al (2017)
87.	Uttarakhand	Nainital	0.01 to 0.66 mg/l	Jha ., et al (2010)
88.	West Bengal	Hooghly	0.01 to 1.158 mg/l	Kundu & Mondal (2009)
89.	West Bengal	Purulia	0.126 to 8.16 mg/l	Behera ., et al (2014)
90.	West Bengal	Bankura	0.01 to 1.6 mg/l	Samal ., et al (2015)
91.	West Bengal	Birbhum	0.023 to 19 mg/l	Batabyal ., et al (2017)

3. Literature study

3.1 Health implications of fluoride on human

Water authorities add fluoride to the municipal water supply, because studies have shown that adding it in areas where fluoride levels in the water are low can reduce the prevalence of tooth decay in the local population. Tooth decay is one of the most common health problems affecting children. Many people worldwide cannot afford the cost of regular dental checks, so adding fluoride can offer savings and benefits to those who need them. However, concerns have arisen regarding fluoride's effect on health, including problems with bones, teeth, and neurological development.

Exposure to high concentrations of fluoride during childhood, when teeth are developing, can result in mild dental fluorosis. There will be tiny white streaks or specks in the enamel of the tooth. This does not affect the health of the teeth, but the discoloration may be noticeable. Breastfeeding infants or making up formula milk with fluoride-free water can help protect small children from fluorosis. Children below the age of 6 years should not use a mouthwash that contains fluoride. Children should be supervised when brushing their teeth to ensure they do not swallow toothpaste.

Excess exposure to fluoride can lead to a bone disease known as skeletal fluorosis. Over many years, this can result in pain and damage to bones and joints. The bones may become hardened and less elastic, increasing the risk of fractures. If the bones thicken and bone tissue accumulates, this can contribute to impaired joint mobility. In some cases, excess fluoride can damage the parathyroid gland. This can result in hyperparathyroidism, which involves uncontrolled secretion of parathyroid hormones, which can result in a depletion of calcium in bone structures and higher-than-normal concentrations of calcium in the blood. Lower calcium concentrations in bones make them more susceptible to fractures.

3.2 Measuring fluoride in water

A simple field method for determination of fluoride in drinking water using handmade fluoride reagent paper impregnated by aluminium quinalizarin complex can be developed. Fluoride reacts with the impregnated reagent paper to release the free ligand with new colour, orange different from that of the complex. The change in the colour, which is proportional to the amount of fluoride, can be measured by the Arsenator. The functionality of the Arsenator which is based on a photometric measurement of spot on the reagent paper is expanded to analyze fluoride.

Figure 1. Handmade fluoride reagent paper impregnated by aluminum quinalizarin

A field deployable colorimetric analyser based on inexpensive smartphone embedded with digital camera for taking photograph of the coloured solution as well as an easy-fit, and compact sample chamber (Akvo Caddisfly). Phones marketed by different smartphone makers can be used. Commercially available zirconium xylenol orange reagent is used for determining fluoride concentration. A software program used with the phone for recording and analyzing the RGB color of the picture. This smartphone method is economical and suited for groundwater fluoride analysis in the field.

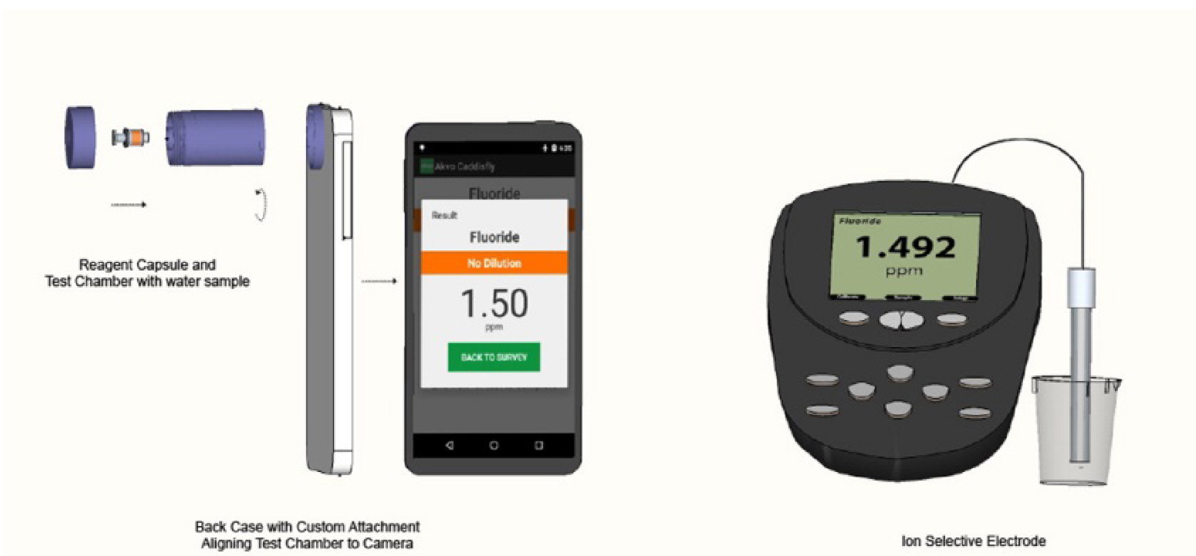

Figure 2. Fluoride analysis by smartphone

The fluoride ion-selective electrode is a very successful potentiometric technique for the determination of fluoride in aqueous solution. Lanthanum fluoride electrode is an example. In the lanthanum fluoride electrode, the sensing element is a crystal of lanthanum fluoride LaF_3, doped with europium fluoride EuF_2 to create lattice vacancies. Such a crystal is an ionic conductor by virtue of the mobility of fluoride ions which jump between lattice vacancies. An electrochemical cell may be constructed using such a crystal as a membrane separating two fluoride solutions. This cell acts as a concentration cell with transference where the fluoride transport number is one. As transference of charge through the crystal is almost exclusively due to fluoride, the electrode is highly specific to fluoride. The only ion which significantly interferes is hydroxide (OH^-). Generally, such "alkaline error" can be avoided by buffering the sample to a pH below 7.

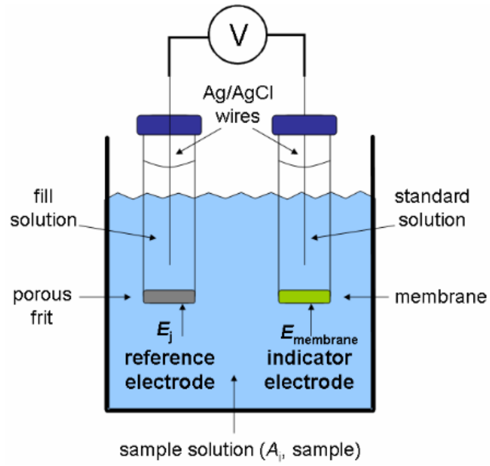

Figure 3. Ion Selective method

Fluoride ion measurement is conventionally done by Ultraviolet spectrophotometer in which sample of water is mixed with small amount of SPADNS in a test tube and exposed to the spectrometer and reading is recorded.

Figure 4. Ultraviolet Spectrometer

4. Results

(1) **Andhra Pradesh:** In Guntur district of Andhra Pradesh the concentration of fluoride in groundwater is constantly increasing but at a slow rate from 0.3 - 1.80 mg/l in 2003 to 0.98 – 2.11 mg/l in 2016. Granite gneisses associated with schists and charnockites are the main lithological formations, which are overlain by black cotton soils. Groundwaters are alkaline, very hard and mostly brackish. Among nine districts of Andhra Pradesh where fluoride concentration of groundwater was measured, none of the districts have fluoride concentration below the permissible limit (1.5mg/l). Also, Kurmapalli watershed area has maximum concentration of fluoride (21 mg/l) which is extremely hazardous.

(2) **Assam:** Concentration of fluoride in Guwahati which is near the Brahmaputra river is higher (0.18 – 6.88 mg/l) than Nalbari (0.02 – 1.56 mg/l) which is away from Brahmaputra. It is stated by Das et al., that groundwater of Guwahati region is recharged by Brahmaputra River which is possibly the cause of higher fluoride concentrations in the groundwater.

(3) **Bihar:** Fluoride concentration of groundwater measured in the indo-gangetic alluvial plains of Bihar was found to be 0.08 to 5.8 mg/l (2018). In the areas of hard rock formations, the fluoride concentration was found to be higher while in the alluvial formations there were less cases of fluoride exceeding the required limit of 1.5 mg/l.

(4) **Chhattisgarh:** High concentrations of fluoride in Dongarhgaon block area in Chhattisgarh (3.3 – 11.3 mg/l) causing fluorosis diseases in humans as well as animals. This high concentration is may be due to deep aquifers >70m which causes the mineralization of bed rock minerals and increase in the concentration of fluoride or may be due to the river which recharges that aquifer (2017).

(5) **New Delhi:** Fluoride in groundwater of southwest Delhi is found to be 0.0 – 1.9 mg/l (2018).

(6) **Haryana:** In Hisar district of Haryana urban areas had lesser concentrations of fluoride (0.1 – 9.2 mg/l) as compare to rural areas which had higher concentrations of fluoride (0.03 – 15.6 mg/l) recorded in (2006-2007). Highest value of fluoride found in Haryana was in Motipura area of Bhiwani district (86 mg/l) Garg ., et al (2009).

(7) Hyderabad: In the Koti area of Hyderabad city fluoride concentration was measured to be 0.06 – 2.05 mg/l (2005).

(8) Karnataka: In three different studies of fluoride in Karnataka, Banglore had most polluted groundwater with (1.47 – 6.12 mg/l) of fluoride (2008).

(9) Kerala: In Palghat area of Kerela fluoride concentration was found to be 0.2 – 5.75 mg/l in 2007.

(10) Madhya Pradesh: In six different areas of Madhya Pradesh only Chhatarpur area had value of 0 – 2.4 mg/l, rest of the areas had very high concentration of fluoride reaching upto 37.1 mg/l in Balaghat, Chhindwara, Dhar, Jhabua, Mandla & Seoni (2017).

(11) Maharashtra: In Yavatmal district of Maharashtra concentration of fluoride in groundwater is found to be decreasing over the period of 9 years from 0.3 – 13.41 mg/l in (2007) to 0.06 – 12.71 mg/l in (2016).

(12) Orissa: Bouden block area of Orissa had fluoride concentration of 0 - 6.4 mg/l in (2011).

(13) Punjab: In two studies of Punjab state Bhatinda had very high concentration of 0 – 14.1 mg/l (2013).

(14) Rajasthan: Ajmer and Jaipur were found to have >15 mg/l of fluoride in groundwater while Nagaur district is highly polluted with fluoride ranging from 8.5 – 28 mg/l (2010).

(15) Tamil Nadu: In Chithar river basin and Kanchipuram district of Tamil Nadu, fluoride concentration was found under the limit of 1.5 mg/l. In Vellore district of Tamil Nadu fluoride concentration was found to be increasing within a time period of 1 year from 0.2 – 3 mg/l in (2017) to 2.15 – 4.91 mg/l in (2018).

(16) Telangana: In Medak district region basaltic rock had higher concentration of fluoride in groundwater.

(17) Uttar Pradesh: In Unnao district, fluoride concentration is found to have increased in 8 years from 1.45 – 3.75 mg/l in (2002) to 0.8 – 13.9 mg/l in (2010).

(18) Uttarakhand: In Nainital area, fluoride concentration in groundwater was found to be 0.01 – 0.66 mg/l in (2010).

(19) West Bengal: Hooghly district has fluoride concentration under the recommended level by WHO. Purulia district of West Bengal has a high concentration of fluoride ranging 0.126 – 8.16 mg/l (2014) while Birbhum region has even higher concentration of 0.023 – 19 mg/l (2017).

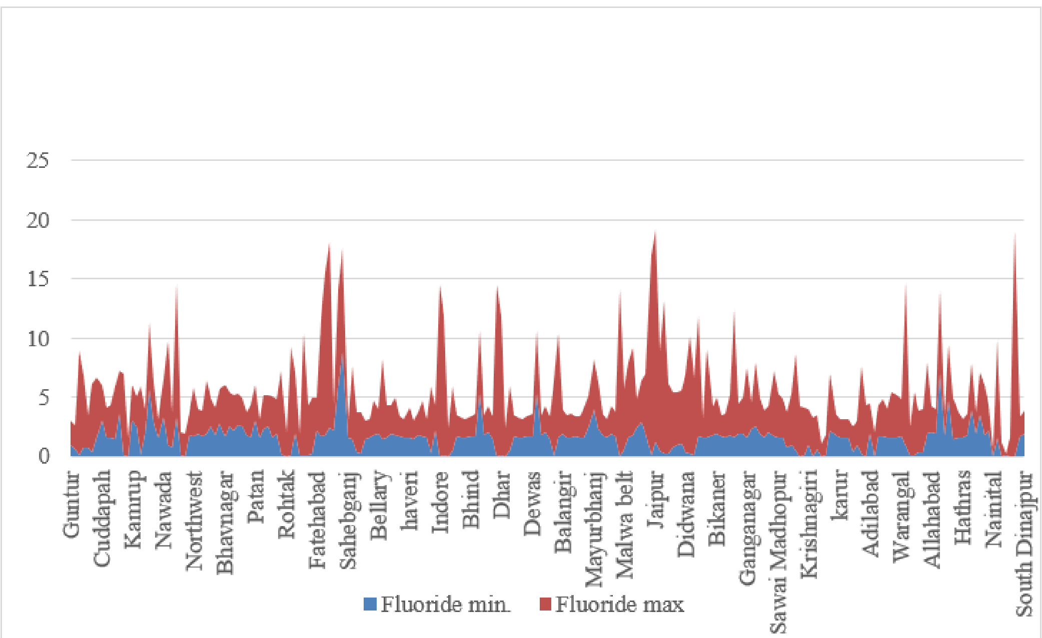

Figure 5. Minimum & Maximum Fluoride Concentration

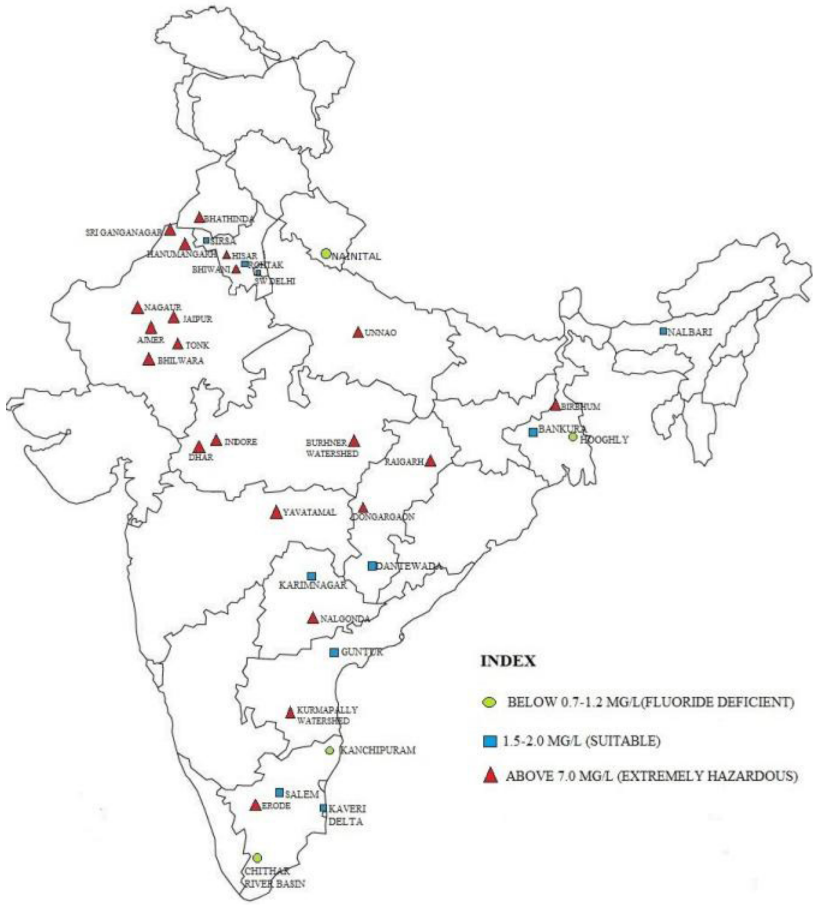

Figure 6. Fluoride concentration in Indian groundwater

5. Analysis and Discussion

The data collected above from 19 different states of India shows variable values of fluoride concentrations in groundwater. Nainital(0.01-0.66 mg/l) in Uttarakhand, Hooghly(0.01-1.15 mg/l) in West Bengal, Kanchipuram(0.05-1.04 mg/l) & Chithar river basin(0.17-1.3 mg/l) in Tamil Nadu have concentration of fluoride below the required limit of (0.7-1.2 mg/l). Lack of fluoride in groundwater may lead to tooth decay which needs to be fulfilled. Bankura district(0.01-1.6 mg/l) of West Bengal, Karimnagar area(1.0-2.0 mg/l) of Telangana, Salem district(0.12-1.66 mg/l) & Cauveri Delta(BDL-1.57 mg/l) of Tamil Nadu, Sirsa district(0.12-1.66 mg/l) & Rohtak district(0.034-2.09 mg/l) of Haryana, Southwest Delhi(0.0-1.9 mg/l), Dantewada(0.08-1.95 mg/l) of Chhattisgarh, Nalbari(0.02-1.56 mg/l) of Assam & Guntur(0.3-1.80 mg/l) district of Andhra Pradesh were found to have exactly near the required limit of 1.5 mg/l of fluoride concentration which is necessary for our health.

Kurmapalli watershed(≤21 mg/l), Wailapally watershed(0.5-7.6 mg/l), Nalgonda(0.1-8.8 mg/l) of Andhra Pradesh, Raigarh(1.0-8.8 mg/l) & Dongarhgaon(3.3-11.3 mg/l) of Chhattisgarh, Hisar(0.03-15.6 mg/l) & Bhiwani(0.14-86 mg/l) of Haryana, Indore(0.0-14.5 mg/l), Dhar(0.18-11.6 mg/l) & Burhner watershed(0.04-14.6 mg/l) of Madhya Pradesh, Yavatamal district(0.06-12.71 mg/l) of Maharashtra, Bhatindha(0.0-14.1 mg/l) in Punjab, Ajmer(0.12-16.9 mg/l), Jaipur(1.20-18 mg/l), Sriganganagar+Hanumangarh(0.5-8.5 mg/l), Bhilwara(0.2-13 mg/l), Nagaur(8.5-28 mg/l) & Tonk(0.3-9.8 mg/l) of Rajasthan, Erode(0.5-8.2 mg/l) in Tamil Nadu, Unnao(0.8-13.9 mg/l) in Uttar Pradesh, Purulia(0.126-8.16 mg/l) & Birbhum(0.023-19 mg/l) in West Bengal were found to have extremely high concentrations of fluoride in groundwater i.e above 7 mg/l.

Seven Districts of Rajasthan were found to be highly polluted >7.0 mg/l with fluoride. Bhiwani district of Punjab was found to be most polluted with fluoride reaching upto 86 mg/l in groundwater. Nagaur district of Rajasthan was also found to have hazardous amount of fluoride in groundwater i.e. 8.5-28 mg/l. Extremely high concentration of fluoride causes diseases like Skeletal and Dental Fluorosis in humans and skin burning diseases in animals also. With increasing depth to water level, the fluoride concentration in groundwater increases in 80% of the cases reviewed. Concentration of fluoride in Guwahati which is near the Brahmaputra River is higher (0.18 – 6.88 mg/l) than Nalbari (0.02 – 1.56 mg/l) which is away from Brahmaputra. There has been no significant change in the fluoride concentration in cases of Yavatamal & Guntur district during past two decades. It was inferred that depth to water level influences the fluoride contamination most among LULC, geology and DTWL.

Hot spring map was created using ArcGIS pro. Hot spring data was taken from Bhukosh portal and later classified based on different temperature ranges from 30°C to 100°C in four different categories. Temperature ranges are as follows 7-30°C,30-45°C, 45-70°C and 70-100°C.

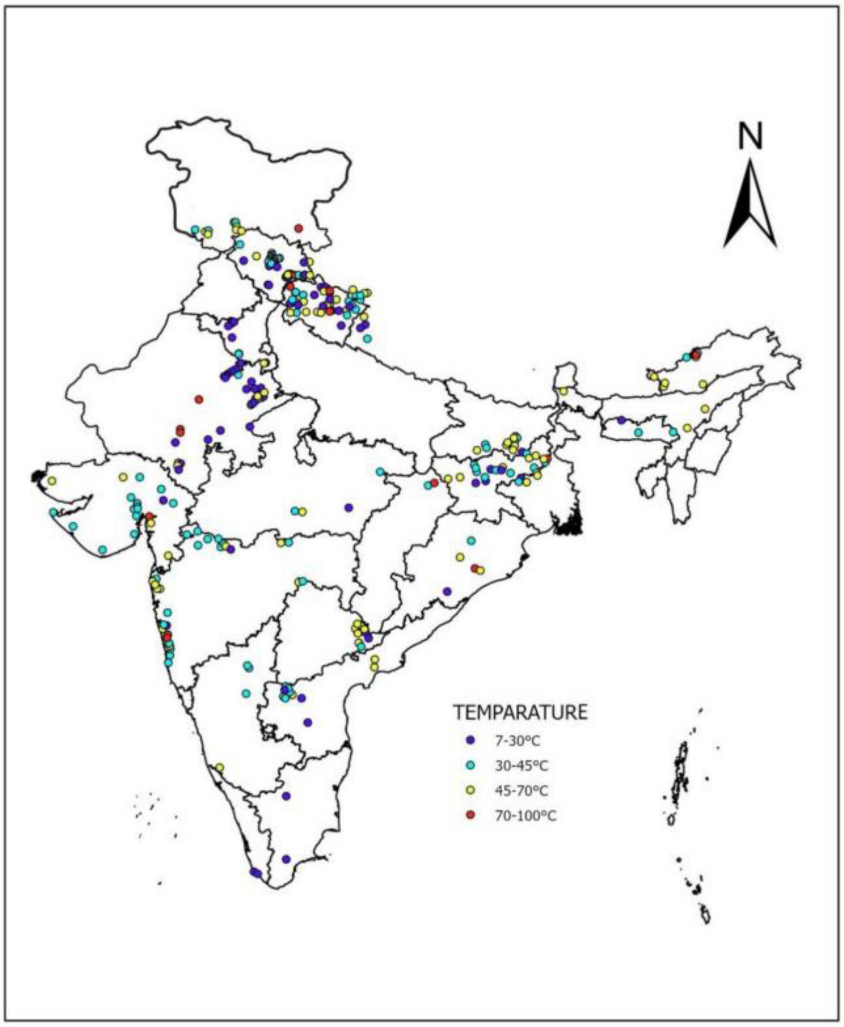

Figure 7. Hot Spring Map of India

6. Conclusions

Fluoride is one of the important micronutrient in humans which is required for strong teeth and bones. There is a good understanding of fluoride health implications and remediation. However, we lack the understanding of fluoride concentration and its relationship with hot springs (groundwater temperatures). Which further raises a question that does increasing groundwater temperature causes fluoride to increase? Or it requires specific fluoride mineral to dissolve faster in the groundwater? Currently, most of the researchers agree to the depth to water level relationship of fluoride in groundwater of India and Geology plays an important role. Aquifer with fluoride minerals increases fluoride dissolution. Anthropogenic sources which are responsible for higher fluoride concentrations are irrigation, pesticides, and fertilizers. Groundwater recharge from river can also cause higher fluoride concentrations. e.g. Guwahati vs Nalbari (Brahmaputra river).

This study found that limited research has been undertaken to understanding the specific processes controlling fluoride provenance in India's groundwater. Hot springs in India are found along the major faults and rifting zones. In India, post rifting aulacogen observed in Western Ghats does show an increase in the groundwater temperature near the western shore in Maharashtra. But when looking at fluoride levels in groundwater for the same location we do not find any anomalous behaviour to support the claim of higher fluoride association with higher groundwater temperatures. It is observed that fluoride concentration in the groundwater of India does not have a significant relationship with the temperature of groundwater i.e. hot springs as in the case of Southern Malawi which is part of East African Rift System, which further suggests that excessive fluoride concentration is dependent on the composition of basement rock rather than temperature of the groundwater.

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