Original Article

Seasonal Variations in the Groundwater Fluoride of Swarna River Basin in Southern India: A GIS-based Study

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ABSTRACT

Objectives: The study aimed (1) to assess fluoride concentration of groundwater along the Swarna river basin in Udupi District; (2) to investigate variations in fluoride concentration with respect to rainfall status in Udupi district; and (3) to develop a spatial distribution map for the groundwater fluoride concentration in Udupi district. **Materials and Methods:** Water samples were procured from 30 different sampling points across three time zones in a year: pre-monsoon, monsoon, and post-monsoon. The samples thus collected were analyzed for fluoride ion concentration using fluoride ion selective electrodes (Orion™). Mean determination readings at each time zone were calculated. Repeated-measures analysis of variance was done to analyze whether there was a difference in the concentration of fluoride over different time zones. **Results:** The mean (SD) pre-monsoon concentration was 0.25 (± 0.07) ppm, whereas the mean monsoon and post-monsoon concentrations were 0.26 (± 0.09) and 0.57 (± 0.23) ppm, respectively. There was a significant increase in post-monsoon fluoride levels when compared with the pre-monsoon and monsoon levels. **Conclusion:** The groundwater fluoride concentration in the Swarna river basin was found acceptable for human consumption at all the sampled sites and across all time zones. As the fluoride concentration was found to be lower than the recommended values for dental caries prevention at most of the sampling sites, use of topical fluorides needs to be encouraged.

Keywords: *Dental fluorosis, drinking water, fluoride, geographic mapping, groundwater pollution*

Introduction

Fluoride is the only known cariostatic elemental anion. It is never found in its elemental form in the nature, by virtue of being the most electronegative of all elements. Fluoride mainly affects skeletal tissues (bones and teeth). It is often called a "double edged sword" due to its narrow range of safety, which, if increased, can become detrimental to health. Fluoride at the concentration of 1 ppm has been proven effective for preventing dental caries.[1,2] Excess ingestion of fluoride above 1.5 ppm or more during teeth formation increases the risk for dental fluorosis (developmental disturbance of enamel), and long-term ingestion of higher levels (8–10 ppm or more) can lead to potentially severe skeletal fluorosis.[3,4] The World Health Organization (WHO) recommends values for fluoride levels in drinking water to be between 0.1 and 0.5 ppm, and the Center for Diseases Control has recommended values between 0.7 and 1.2 ppm corresponding to the regional temperature.[5-8] Around 200 million people in 25 nations are at a risk of developing fluorosis due to

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higher fluoride contents in drinking water. In India, the states of Andhra Pradesh, Rajasthan, Punjab, Gujarat, Haryana, Tamil Nadu, and Uttar Pradesh are gravely affected.[4]

Udupi district, situated on the Indian western coast, experiences a temperature variation between 22°C and 36°C and receives an average annual rainfall of about 4035 mm.[9] Swarna is the main river of Udupi district with a catchment area of 327 km^2. The Swarna river originates in the Western Ghats and drains in the Arabian Sea with a total length of 61.05 km. The river is called "Yennehole" in the initial reaches and later "Swarna" after its confluence with a tributary named "Kaud-hole."[10]

The majority of the population of Udupi district depends on Swarna river water for drinking, agricultural, and industrial purposes. In urban areas, the Udupi municipality treats river water and then supplies it for domestic purposes. However, rural areas largely depend on groundwater of the river basin. Diverse ecosystems and climatic differences can influence the availability and intake of fluoride. Therefore, healthcare professionals and researchers need to obtain pertinent knowledge regarding fluoride concentration in the drinking water. Many studies have evaluated the fluoride contamination in groundwater across India.[11-13] A thorough search of the literature revealed only a few studies undertaken to assess fluoride concentration in Udupi district.[14-16] However, fluoride content in groundwater of the Swarna river basin has not yet been reported. As fluoride in abnormal concentrations is known to affect oral hard tissues, an analysis of the same as well as any changes occurring due to monsoon will help in the assessment of water quality of river basin.

Hence, this study aimed to assess the fluoride concentrations in the groundwater along the Swarna river course in Udupi district and to investigate any variations in fluoride concentrations with respect to rainfall status in Udupi district. The study also aims to develop a spatial distribution map for the groundwater fluoride concentration in Udupi district using Geographic Information System (GIS) software.

Materials and Methods

The study was conducted for a 10-month period: from January 2019 to October 2019 along the course of Swarna river in Udupi district. The water samples were collected for three seasons: pre-monsoon in March 2019, monsoon in July 2019, and post-monsoon season in October 2019.

We identified 30 sampling points according to the river flow and in consultation with geological experts involved in the study [Figure 1]. We also referred the regional toposheet of Udupi district so as to cover the maximum catchment areas of all the topographic locations such as hills and plains from which the sample collection sites were chosen randomly. Water sample collection was done using wide mouth polypropylene (PP Grade, 500 mL capacity) bottles.

Bottles were processed in the laboratory in advance to sample collection. All the bottles were first rinsed with dilute nitric acid (10%) followed by double distilled water and dried overnight in a laminar flow chamber. Bottles were then tightly capped and labeled with the sampling site number and stored until further use.

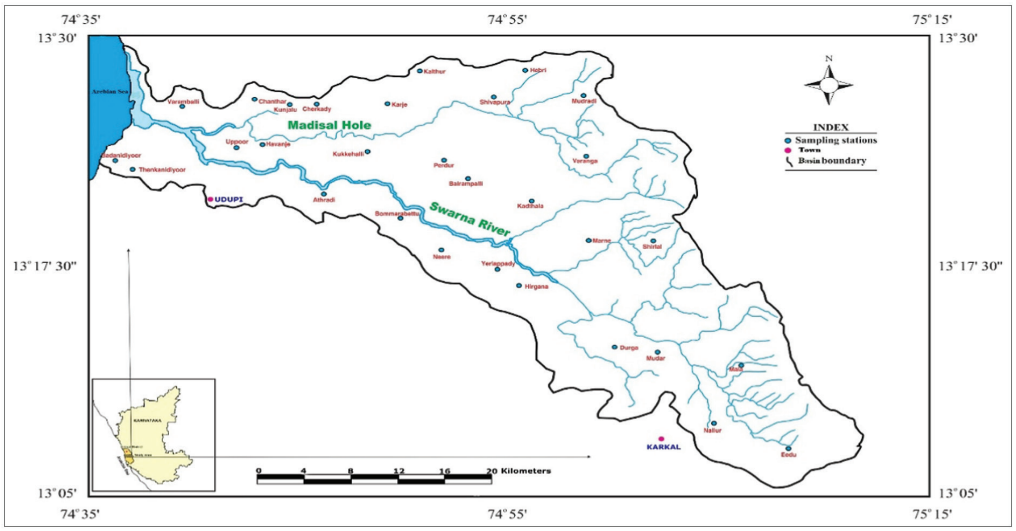

Figure 1: Study area map with sample collection sites

At the time of sample collection, 500 mL of water from each site was collected, before which the bottle was rinsed three times with sample water and then filled without leaving any air bubble. Fluoride analysis was done using fluoride ion selective electrodes (Orion™). It is a fluoride ion selective electrode used to detect the concentration of fluoride ions in the water samples (User Guide Fluoride Ion Selective Electrode 2019). The direct calibration technique was used for measuring fluoride ion concentration.

Calibration of the instrument was done before starting the procedure by using a series of standards. Three standards that bracketed the entire sample range were prepared that differed in concentration by a factor of 10. The concentrations of these standards were 0.5, 1, and 2 ppm. The standards were prepared by the serial dilution method. All standards were kept at the same temperature as that of samples. Once the instrument was calibrated and was ready to use, the fluoride analysis was started.

The measuring electrode was rinsed with deionized water, blot dry, and then kept ready to be placed into the sample. A 200 mL beaker was taken, in which 30 mL of sample was added followed by 30 mL of buffer. The total ionic strength adjustment buffer was used as a buffer solution and was added to each solution to make sure that standards and samples have equal ionic strength. The solution was stirred using a magnetic stirrer. The measuring electrode was then lowered into the sample. After some time, a reading that was stable was displayed on the screen. The reading showed the concentration of fluoride in sample. The experiment was repeated if any disagreement or technical issue was reported during the procedure.

Statistical analysis

Data obtained were compiled on an MS Office Excel Sheet (v 2010, Washington, USA). Statistical analysis was done using Statistical Package for Social Sciences (SPSS v 21.0, IBM). Descriptive statistics like mean and SD for numerical data have been depicted. Inter-group comparison was done using Kruskal–Wallis analysis of variance (ANOVA), followed by pair-wise comparison using the Mann–Whitney *U*-test. Statistical significance was set at 5% level of significance ($P < 0.05$). Keeping α error at 5% and β error at 20% gives a power to the study as 80%.

QGIS software (Quantum GIS Version 2.18) was further used to represent the study results on a spatial map. They were made by interpolation of the test results across various points inside the map with the area under consideration as boundaries. The legend represents the concentration at which fluoride exists in the water before and after the monsoon.

Results

The fluoride concentrations ranged from 0.2 to 0.5 ppm with a mean of 0.26 (±0.09 SD) for all sampling sites in pre-monsoon. The range during monsoon was 0.2–0.5 ppm with a mean of 0.25 (±0.07 SD) and 0.2–0.9 ppm with a mean of 0.57 (±0.23 SD) during the post-monsoon.

Table 1 and Figure 2 show the concentration of fluoride across three seasons (in ppm).

Normality of numerical data was checked using the Shapiro–Wilk test which showed that the data did not follow a normal curve. Thus, non-parametric tests were used for comparisons. Inter-group comparison done using Kruskal–Wallis ANOVA determined that mean *F* levels differed statistically significantly between time points (F (1.214, 48.008) = 21.032, $P < 0.0005$) [Table 1]. *Post hoc* tests using the Mann–Whitney *U*-test revealed that a slight reduction in fluoride levels was seen from pre-monsoon to monsoon (0.27 ± 0.877 vs. 0.25 ± 0.0731 mg/L, respectively), which was not statistically significant ($P = 0.406$). However, post-monsoon fluoride levels had increased to 0.577 ± 0.225 mg/L, which was significantly different from pre-monsoon ($P < 0.000$) and monsoon ($P < 0.000$) concentrations [Table 2]. Thus, there was a significant increase in post-monsoon fluoride levels in the Swarna river basin. Also, statistically insignificant decrease in fluoride levels was seen during monsoon when compared with pre-monsoon fluoride levels.

The physicochemical parameters of water quality such as pH, dissolved oxygen (DO), conductivity (EC), total dissolved solids (TDS), resistivity, and salinity post-monsoon are presented in Table 3. In the study area, pH values ranged from 5.55 to 7.47, with 63% of sample sites recording values below the recommended 6.5. DO ranged between 7.15 and 11.27 mg/L, with all sample sites recording above the desired limit of 6.5–8 mg/L. Electrical conductivity too was well within the desirable limit in all, except 3 of 30 samples. These too were within the maximum permissible limit of 1400 µs/cm. TDS varied from 31.61 to 1258.00 mg/L. These values clearly indicate that the study area falls under low range. Resistivity ranged from 2.49 to 1995.00 kΩ with a median value of 19.18. The salinity in the water samples ranged from 0.01% to 0.62% with a median value of 0.03%.

Table 4 shows the physicochemical parameters of groundwater samples in correlation matrix. Positive

Table 1: Concentration of fluoride across three seasons (in ppm) and analysis for difference in fluoride concentration over three seasons

S. no.	Sampling point	Pre-monsoon	Monsoon	Post-monsoon
1.	Neere	0.2	0.4	0.8
2.	Durga	0.4	0.5	0.6
3.	Mudar	0.4	0.3	0.8
4.	Shirlal	0.2	0.3	0.8
5.	Kukkehalli	0.2	0.3	0.7
6.	Bairampalli	0.2	0.3	0.7
7.	Shivapura	0.2	0.2	0.7
8.	Nalluru	0.2	0.2	0.4
9.	Kalthuru	0.2	0.2	0.7
10.	Mudradi	0.2	0.2	0.8
11.	Mala	0.3	0.2	0.2
12.	Varanga	0.2	0.2	0.6
13.	Bomarbettu	0.2	0.3	0.7
14.	Kadthala	0.3	0.2	0.2
15.	Eedu	0.3	0.2	0.7
16.	Chanthar	0.4	0.2	0.5
17.	Yerlapaddy	0.3	0.3	0.2
18.	Hirgana	0.2	0.2	0.7
19.	Hebri	0.5	0.3	0.7
20.	Havanje	0.3	0.2	0.2
21.	Tenkanidiyoor	0.3	0.2	0.9
22.	Kunjalu	0.3	0.2	0.7
23.	Cherkady	0.4	0.3	0.2
24.	Athradi	0.2	0.2	0.7
25.	Marne	0.2	0.3	0.7
26.	Pradanidiyoor	0.2	0.2	0.2
27.	Perduru	0.2	0.2	0.3
28.	Uppor	0.3	0.2	0.7
29.	Karje	0.4	0.3	0.5
30.	Varamballi	0.2	0.2	0.7
Mean (SD)		0.26 (0.09)	0.25 (0.07)	0.577 (0.23)
Mean rank		37.05	33.35	66.10

χ^2 value = 31.450. *P*-value of KW ANOVA is 0.000**

**Statistically highly significant difference (P<0.01)

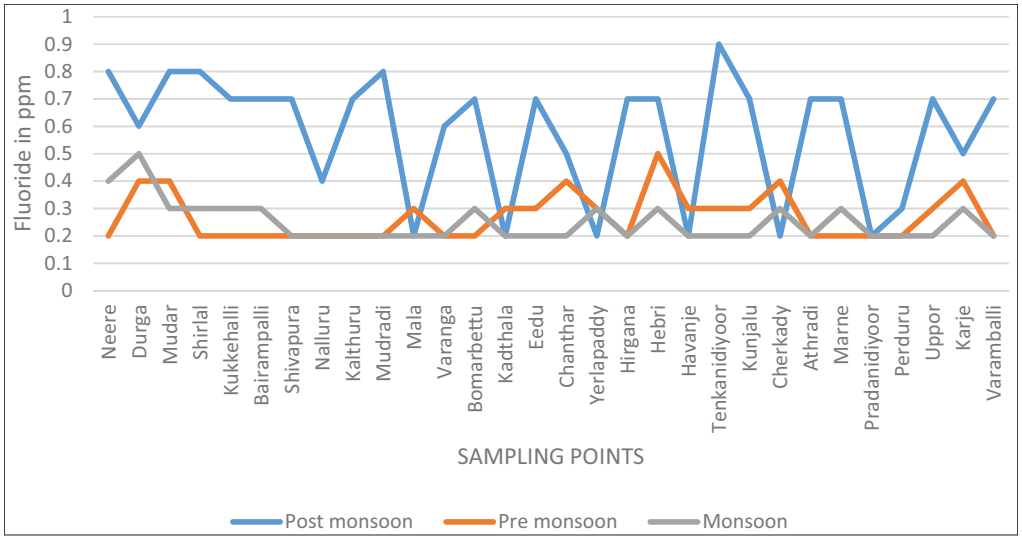

Figure 2: Concentration of fluoride across three seasons (in ppm)

Table 2: Pairwise comparison in fluoride concentration over three seasons

		Mann–Whitney *U*-values	*Z*-value	*P*-value of Mann–Whitney *U*-test
Pre-monsoon	Monsoon	400.00	−0.83	0.406
Pre-monsoon	Post-monsoon	146.50	−4.64	0.000**
Monsoon	Post-monsoon	135.50	−4.85	0.000**

**Statistically highly significant difference (P<0.01)

Table 3: Physicochemical parameters of water samples collected in monsoon season

	Dissolved oxygen	pH	Conductivity	Total dissolved solids	Resistivity	Salinity
N	30	30	30	30	30	30
Minimum	7.15	5.55	23.90	11.61	2.49	0.01
Maximum	11.27	7.47	510.00	371.00	1995.00	0.62
Mean	9.49	6.32	126.59	67.95	152.78	0.08
Median	9.55	6.34	60.10	29.50	19.18	0.03
Standard deviation	1.12	0.49	134.87	8.44	441.40	0.13

Table 4: Physicochemical parameters of groundwater samples in correlation matrix (values in bold indicate significant correlation)

	DO	pH	Conductivity	TDS	Resistivity	Salinity
DO	1					
pH	0.399*	1				
Conductivity	−0.212	−0.093	1			
TDS	−0.221	−0.109	**0.836****	1		
Resistivity	−0.224	−0.254	**0.660****	**0.787****	1	
Salinity	−0.383*	−0.243	**0.813****	**0.809****	**0.700****	1

DO = dissolved oxygen, pH = acidity, TDS = total dissolved solids

**Correlation is significant at the 0.01 level (two-tailed)

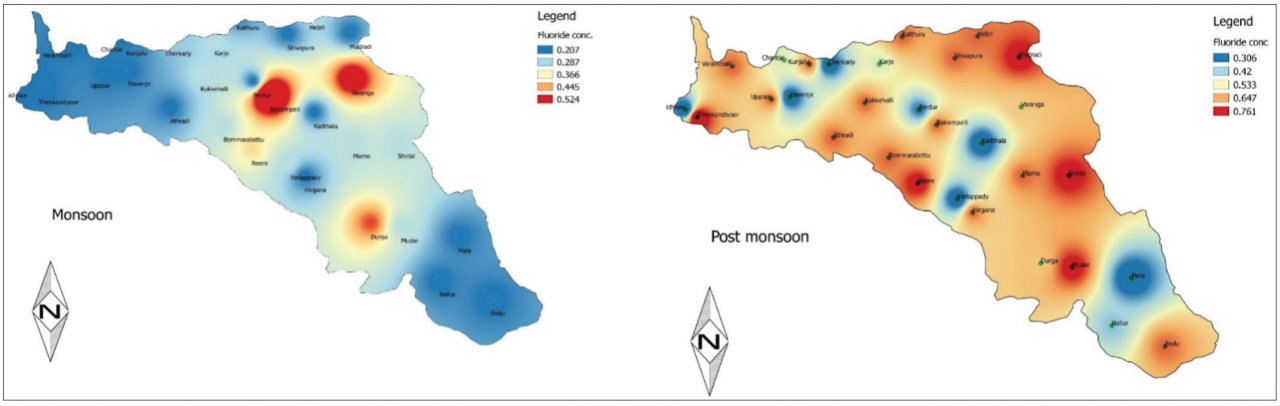

Figure 3: Fluoride concentration during monsoon and post-monsoon

correlation between conductivity with TDS, resistivity, and salinity was observed at the 0.01 level. Positive correlation was also observed between TDS and resistivity and salinity at the 0.01 level.

Figure 3 depicts spatial distribution of the monsoon and post-monsoon groundwater fluoride concentrations in Udupi district using GIS software (QGIS).

Discussion

The present investigation was conducted to assess the groundwater fluoride concentration of Swarna river course in Udupi district and to check the effect of rainfall on their concentration. Results showed that the fluoride concentration was within the acceptable limits as per the specifications for drinking water by the Bureau of Indian Standards (BIS) for all the sampling points and across all the seasons.[17] It recommends 1.5 ppm of fluoride, whereas the Indian Council of Medical Research (ICMR) recommends 1.0 ppm of fluoride in water as optimal for consumption.[16]

The maximum fluoride concentration found in the present study was 0.9 ppm in Tenkanidiyoor in

post-monsoon season. However, maximum fluoride ions concentration in any site during pre-monsoon and monsoon seasons was 0.5 ppm.

The present study findings were in accordance with a similar study done to assess the fluoride concentration in groundwater from four regions of Karnataka and reported the mean concentration in Udupi district to be 0.37 ppm. Accordingly, the fluoride concentration was least in the south-west region of Karnataka (a mean value of 0.41 ppm) where Udupi is situated.[11] A similar finding was also found in another study which reported that fluoride concentrations in most of the groundwater samples from public wells of Udupi were less than the desirable limit of drinking-water standards.[13] However, in the study conducted by Deepika *et al.*,[12] the groundwater fluoride level in Udupi district was found to be in the range of 0.2–2.5 (mean=1.3). This could be due to the collection of samples from different sources such as aquifers.

There was a statistically significant increase in post-monsoon fluoride levels when compared with pre-monsoon and monsoon concentrations. Udupi district lies in close proximity to the Western Ghats and experiences heavy rainfall during the year, which may have led to a possible dilution of groundwater.

The role of fluoride in inhibiting or even in the reversal of the initiation and progression of dental caries is a known fact. The WHO has ascertained that dental caries is globally widespread and advises addition of fluoride for water consumption where the occurrence of natural fluoride is below the optimal levels (Indian Standard Drinking Water specification).[18] A small quantity of fluoride in water consumption can make teeth stronger and aid in the prevention of dental caries.[19] However, water fluoridation has been controversial in various communities and it is neither feasible nor practiced in India.

It is noteworthy to mention here that burden of dental caries and consequences of untreated dental caries are still notably high among schoolchildren in Udupi.[20] The prevalence of missing and decayed deciduous teeth among males and females was found to be 58% and 67.6%, respectively. Owing to a relatively lower fluoride level in the groundwater in this region, it is recommended to use some form of topical fluoridation methods to prevent dental caries among schoolchildren. In those areas with below or optimum levels of fluoride in drinking water, topical fluorides are a method of choice for caries reduction in children. Typical methods of professional topical fluoride application include fluoride varnishes and gels, while the latter are also used as self-applied along with fluoridated toothpastes and rinses.

Conclusion

In conclusion, the groundwater fluoride concentration of Swarna river basin was found to be acceptable for human consumption at all the sampled sites and across all time zones of the year. As the fluoride content was found to be very low in most of the sampling sites, there is need for healthcare professionals to ensure that the local community is adequately educated and judicial use of fluoride supplements to be considered.

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Conflicts of interest

All authors report no conflicts of interest relevant to this article.

Authors' contributions

Dr. Kush Kalra contributed substantially to the conception or design of the work; performing all data collection and drafting the work. Dr. Ramprasad Vasthare contributed substantially to the conception or design of the work; drafting of the work and revising it critically for important intellectual content; final approval of the version to be published. Dr. Vishnu Sharma contributed to the design of the work and revising it critically for important intellectual content; final approval of the version to be published. Dr. Udayashankar contributed to the data acquisition, analysis, or interpretation of data GIS handling and final approval of the version to be published. Dr. Nishu contributed substantially to the statistical analysis; drafting and final approval of the version to be published. Dr. Prajna P. Nayak contributed to the interpretation of data, revising it critically for important intellectual content; drafting and proofreading the article and final approval of the version to be published.

Ethical policy and institutional review board statement

Approved.

Patient declaration of consent

Not applicable.

Data availability statement

The datasets used during the current study are available from the corresponding author on reasonable request.

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