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Research Article

A baseline study on the distribution of fluoride in drinking water and its health risk assessment in Industrial areas of Sivakasi, India

Mohammad Suhail Meer*
Centre for Remote Sensing and Geoinformatics, Sathyabama Institute of Science and Technology,Chennai-600119 (Tamil Nadu), India
Krishnan Vijayaprabhakaran
Centre for earth and atmospheric Science, Sathyabama Institute of Science and Technology,Chennai-600119 (Tamil Nadu), India
Selva Ganapathy Velusamy
Department of Geology, University of Madras,Guindy Campus, Chennai (Tamil Nadu), India
Raja Shanmugavel
Department of Geology, University of Madras, Guindy Campus, Chennai (Tamil Nadu), India
Machakalai Rajesh Kumar
Centre for Earth and Atmospheric Science, Sathyabama Institute of Science and Technology,Chennai-600119 (Tamil Nadu), India

*Corresponding author. Email: mohdsuhailrs@gmail.com

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Abstract
Sivakasi, popularly known as "Little Japan," is a town in the southern region of Tamil Nadu. The study area has a semi-arid tropical monsoon climate. The inhabitants depend heavily on groundwater, which is used extensively for irrigation, drinking, and domestic. The present research aimed to evaluate groundwater quality in Sivakasi, focusing on fluoride levels and major ions, providing essential information on the non-carcinogenic risks posed to residents, particularly adults, and the suitability of water for both drinking and agriculture. Fluoride concentration and the most important cations and anions were analyzed in 32 groundwater samples. The major cations and anions present in field samples are in the order of abundance: Cl> SO4> HCO3> Na > Mg >Ca> K. For drinking purposes, groundwater quality varies from moderate to poor, and over 70% of groundwater tests are out of condition for agricultural water supply. Fluoride levels in the samples from the study area ranged from 0.00 to 2.60 mg/l, with an average value of 1.60 mg/l. The hazardous Quotient (HQ) value for infants ranged from 0.00 E+00 to 1.69 E+00, children from 0.00 E+00 to 1.80 E+00, and for adults from 0.00E+00 to 1.88E+00. Additionally, the adults were more susceptible to non-carcinogenic threats than infants and children. This study on groundwater quality in Sivakasi highlights risks to health from excessive fluoride levels, particularly for adults, making it important for disaster mitigation. Understanding the non-carcinogenic hazards of contaminated water can drive disaster preparedness actions and resource allocation, emphasizing the need for secure water sources and resilient water management methods in the semiarid region.

Keywords: Hazardous Quotient, Risk Assessment, Fluoride, Drinking water, Sivakasi

INTRODUCTION

The scarcity of viable freshwater resources presents a substantial worldwide obstacle, as less than 3% of the Earth's freshwater is readily available for human utilization. Furthermore, fewer than 1% is deemed appropriate for human consumption within this %age. Given the limited availability of water, groundwater has become an essential source of drinking water, serving as a lifeline for more than a third of the global population. Groundwater is crucial in fulfilling human water requirements, especially considering the significant challenge of worldwide limited and appropriate freshwater resources (Emenike *et al.,* 2017; Saleh *et al.,* 2019;WHO, 2017). Groundwater contamination occurs when contaminants are introduced into subsurface aquifers, leading to a substantial change in the chemical composition of the water. The environmental problems with groundwater have extensive ramifications, impacting both human well-being and economic sustainability, especially concerning domestic water consumption, farming, and the provision of drinking water(Li*et al.,* 2021; Adimalla and Wu, 2019; Adimalla,2020; Adimalla*et al*.,2018; Ramya and Elango,2018, Thapa *et al*.,2017; Zhang *et al*.,2018). The over-exploitation of groundwater causes it to decline to lower water levels, resulting in seawater intrusions in coastal regions (Siddha, 2020). The superiority of the groundwater in these regions is extremely subject to question; researchers have done many studies to estimate the appropriateness of the groundwater in dry, semi-arid, and coastal regions (Adimalla, 2020; Adimalla, 2019; Adimalla, 2019a; Ramya and Elango, 2019). The investigations were centred on analyzing the hydrogeochemical properties of the groundwater to identify pollutants and determine their origins. The groundwater was found to contain very small amounts of fluoride, a particular anion. Its presence is significant since it might potentially affect human health. According to Shahjad*et al*. (2021), fluoride ions can be introduced into the human body through food, water, and breathing. Hence, it is imperative to conduct a hydrogeochemical investigation of groundwater in these areas to comprehend the possible health consequences linked to the existence of fluoride and other pollutants.

Fluorosis is a disease affecting millionsworldwide due to consuming fluoride-contaminated groundwater (Srivastava and Flora, 2020; Qasemi,2019; Sarma, 2018,2009). Since fluoride has no colour, taste, or smell when dissolved in water, a concentration of 0.4 to 1.0 mg/L is beneficial to human health since it helps prevent tooth cavities by accelerating the calcification of dental enamel (Pradhan & Biswal, 2018). Fluoride levels over 1.5 mg/L have harmful effects on health, leading to conditions such as dental and skeletal fluorosis, osteoporosis, arthritis, fragile bones, specific forms of cancer, infertility, Alzheimer's disease, brain damage, and thyroid dysfunction (Nur *et al.,* 2014; Chen and Qian,2016). According to the World Health Organisation (WHO), the recommended level of fluoride in drinking water is between 0.5 and 1.5 milligrams per litre (mg/L) (World Health Organization, 2004).

Researchers have observed that water with high pH levels can enhance the solubility of fluoride and the ion exchange between fluoride ions and hydroxyl ions, leading to an elevation in the concentration of fluoride in groundwater, especially with higher levels of bicarbonate and sodium (Raju, 2017; Adimalla and Venkatayogi, 2017). It has been reported that the children in Agra, Uttar Pradesh, are more vulnerable to non-carcinogenic threats than newborns and adults due to excessive fluoride levels in their drinking water (Shahjad*et al.,* 2021). Fluorosis endangers almost 40 million people in India (Chinoy, 1991). Fluoride contamination in water was extremely high (38 mg/l) in India's groundwater (Susheela, 1984). Natural pollution is the main cause of the amount of fluoride in groundwater. However, the method of dissolution is still poorly understood (Binbin *et al.,* 2005; Zhang, 2003). A study conducted in Bardaskan County, Iran, by(Radfarda*et al*., 2019) reveals concerning fluoride levels in drinking water, with concentrations falling within WHO guidelines except in one instance. The health risk assessment indicates that a significant portion of the population, particularly infants and children, may face potential health issues due to elevated levels.

The present study aimed to assess the quantitative and qualitative approach to elevated fluoridepresent in groundwater of Sivakasi region, in the Viruthunagar district,whichhas a semi-arid environment with Archean Charnockites and Hornblende-biotite gneiss forming the aquifers.

MATERIALS AND METHODS

Study area and sampling

Sivakasi is a town in the Virudhunagar district of Tamil Nadu's southern state. It is situated west of Sattur and east of the Western Ghats. It is characterized by disjointed and weathered Archean rocks such as Charnockites and Hornblende-biotite gneisses from aquifers.The sampling points are highlighted in the base map of the study region.Groundwater samples were collected within Sivakasicity in August 2019 (Fig. 1). Then, samples were analyzed in the region around Sivakasi to assess its groundwater quality.

Thirty-two samples were collected in polyethylene bottles (500 mL) in the study area.The bottles were cleaned using methanol before the sample was collectedin 2021.Then, the samples were analyzed for various different hydrogeochemical parameters such as Potential of Hydrogen(pH), Electrical Conductivity (EC), (Total Organic Carbon) ToC, and (Total Dissolved Solids) TDS, as well as turbidity in the Lab according to the methods of the American Public Health Association (APHA, 2012; APHA *et al.,* 2017)Fluoride (F-) ions were measured immediately withusing the Orion Ion hand-held electrodes (Chidambaram *et al.,* 2013).Other hydrogeochemical conditions (major cations and anions) such as potassium, magnesium, calcium, sodium, chloride, fluoride, sulfate, and bicarbonate were also determined in the laboratory.Colorimetry was usedto examine the fluoride levels, while a Flame photometer was used to quantify sodium and potassium (Collins, 1961).The methodology described involves titrimetric analysis for determining calcium, magnesium, bicarbonate, and chloride levels in water samples (Harris, 2015; APHA *et al.,* 2017).

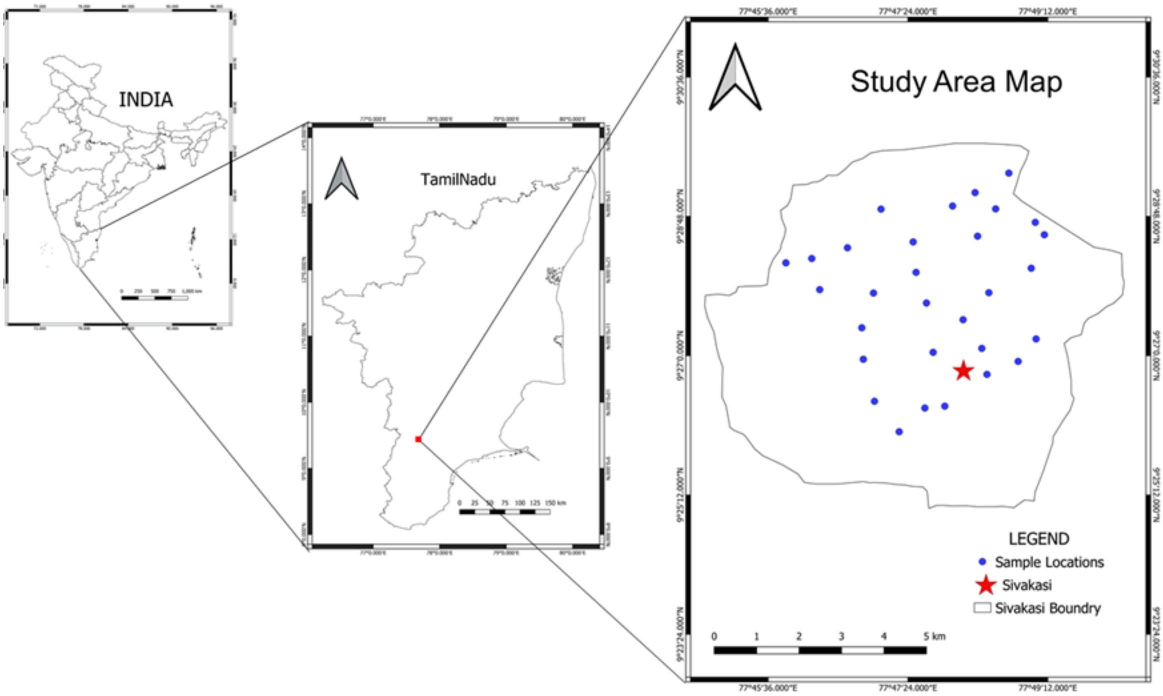

Fig. 1. *Study area base map showing sampling location in Sivakasi city.*

Data analysis using ionic Balance

The obtained data was used to perform an ionic balance calculation, reducing the possibilityof errors in the analysis. The findings will help to develop successful initiatives to improve water quality in Sivakasi.

Water quality for drinking purposes

Weighted Arithmetic Index WAI

Brown *et al*.(1972) developed an equation (eq-1) to measure water quality. Later, (Ramyapriya Ramesh *et al.,* 2017) used the same methodto analyze the quality of groundwater and surface water in the Cauvery region.

DWQI= Σ(Wn*Qn) Eq. 1

Wn = Nth parameter's unit weight, Qn = The corresponding parameter's sub-index

The WQI is used extensively in several places around the world to assess whether groundwater is safe for drinking purposes (Wu and Sun, 2016; Khan and Jhariya, 2017). The assigned weightage, calculated relative weightage, and standard values for each parameter are listed in Table 1 and the computed WQI values are divided into six categories: excellent, good, moderate, poor, extremely poor, and unfit for human consumption (Khan and Jhariya, 2017).

Nemerow's Pollution Index (NPI)

The basic method for measuring groundwater quality is Nemerow's pollution index (Sudhakar, 2015). The equation (eq-2) used to assess groundwater quality is provided below.

N P I = Ci / Li Eq. 2

Ci= i^{th} parameter's concentration

Li= i^{th} parameter's permissible limit

If the calculated value is less than 1, the parameter is not a pollutant in the water; however, if the value is greater than 1, the parameter can become a pollutant in the water.

Groundwater quality for irrigation purposes

Water with dissolved minerals is needed for irrigation, but if the dissolved nutrients' value exceeds the allowable limits, it becomes a pollutant, and therefore water with a high nutrient content is incompatible with consumption. Sodium Absorption Ratio (SAR), Kelly Ratio (KR) and Magnesium Hardness %age (MHP) were calculated to assess the suitability of groundwater for irrigation.

Sodium Absorption Ratio (SAR)

In agricultural soil, sodium, along with calcium and magnesium, has the potential of infiltration (Adimalla and Wu, 2019; Adimalla and Qian, 2019a; LA, 1954; Ramya and Elango, 2018) and the amount of sodium detected in the soil may affect the permeability of groundwater. Sodium Absorption values were calculated by using the formula (Eq.3) proposed by (LA 1954).

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \quad \text{Eq. 3}$$

LA (1954) classed water samples with SAR values less than ten as excellent for irrigation, ten to eighteen as good, eighteen to twenty-six as fair, and twenty-six or more as inappropriate for irrigation.

Kelly Ratio (KR)

Kelly (1954) created an equation to classify water used for irrigationby usingsodium cations in equation 4 to balance the addition of calcium and magnesium. Due to high Na+ concentrations and the possibility of dispersive soils, water with a KR of more than one is generally considered unacceptable for irrigation, while water with a KR of less than one is regarded as good for irrigation.

$$k\,R = \frac{Na}{ca + Mg} \qquad \text{Eq. 4}$$

Magnesium Hardness %age (MHP)

The equilibrium between magnesium and calcium can be observed in both water and soil, and this relationship (Paliwal, 1972) established an equation (equation-5) to determine the MHP value of water.

$$MHP = \frac{Mg}{ca + Mg} \times 100 \qquad \text{Eq. 5}$$

Sodium %age of sodium (Na)

The ratio of calcium to sodium and sodium in the soil is used to determine the permeability of the soil. Sodium and calcium and magnesium ions form flocculates, obstructing water flow. Eq-6 was used to calculate the Na%.

$$Na\% = \frac{Na+k}{ca+Mg+Na+k} \times 100 \qquad \text{Eq.6}$$

Health Risk Assessment (H R A)

Health risk assessments are commonly used to evaluate the likelihood of adversehealth consequences and to quantify the harm to a person's health. The USEPA has developed a technique for assessing the non-carcinogenic risk of heavy metals in drinking water on humans over time (USEPA, 2004). The two most common ways humans are exposed to water are through skin contact and water consumption. Since many of the components that contribute to the hazards to human health through cutaneous contact are unclear, only drinking water is used in this study to evaluate the danger to human health. Eq-1 can be used to calculate the chronic daily intake (CDI) of water. Table 2 shows the values used in the CDI calculation (Table 2).

Table 1. Parameters along with its calculated Wi for WAI calculation.

Parameters	Standards WHO (2017)	Unit Weight (Wi)
pH	8.50	0.469
TDS	500	0.008
Ca	75	0.053
Mg	50	0.08
SO_4	200	0.02
Na	200	0.02
K	12	0.332
Cl	200	0.02

CDI=(C×IR×EF×ED)/(BW×AT) Eq.7

HQ=C D I / RfD Eq. 8

The hazardous quotient (HQ), for oral ingestion of Eq-8, is the ratio of the reference dose (RfD) to the CDI. The USEPA's Integrated Risk Information System database lists 0.06 (mcg kg1 d1) as the fluoride reference dose level (RfD). Humans are at considerable non-carcinogenic risk if the HQ value is one or higher; otherwise, they are not at significant non-carcinogenic risk.

RESULTS AND DISCUSSION

Table 3 presents the hydrogeochemical parameters of Sivakasi town, encompassing the minimum, maximum, and average values. The statistical analysis of these parameters offers a comprehensive understanding of the groundwater dynamics in the region, elucidating significant trends and variations. The outcomes contribute to the characterization of the hydrogeochemical profile, crucial for assessing the overall quality and behavior of the groundwater in Sivakasi town. The principal ion values were compared to the (40) drinking requirements (set at 40). Averaging the values deter-

Table. 2. Factors used in calculation with units and values (USPEA 2004, 2001)

Factor	Expansions	Unit	Infants	Children	Adults
E	Chronic daily intake	mg/kg/day	-	-	-
CPW	Concentration of the metal	mg / l	-	-	-
IR	Ingestion rate	L/day	0.30	0.78	2.50
ED	Exposure duration	Years	< 1	12	64
EF	Exposure Frequency	Days/Years	365	365	365
ABW	Average Body Weight	kg	6.90	18.70	57.50
AET	Average Time	Days	365	4380	23360

E (Chronic daily intake), C P W(Concentration of the metal), IR(Ingestion rate), ER(Exposure Frequency), ABW(Average Body Weight), AET (Average Time) mines the order. Cl> SO4 > HCO3 > Na > Mg > Ca> k are the the majority abundant cations and anions in samples of groundwater. The analysis of groundwater samples demonstrated a range of calcium concentrations, spanning from 20 to 204 mg/l. Notably, this spectrum falls consistently below the upper acceptable limit established by the World Health Organization (WHO) in 2017.The significant presence of calcium-bearing rock in the groundwater underscores its role as a crucial contributor to the calcium content observed in the samples. The exchange mechanism between calcium-bearing rock and water is pivotal, as it directly influences the calcium levels available for absorption by the human body (Edjah*et al.,*2023).It is essential to highlight the relevance of calcium in water concerning human health. The ability of body to absorb calcium is directly linked to the calcium content in water. Therefore, monitoring and understanding calcium dynamics in groundwater is crucial for public health initiatives (Hoenderop *et al*.,2005).

The magnesium content in groundwater in the Sivakasi region is primarily attributed to Mg-containing minerals, silicate weathering, and industrial wastes (Prakash, 2017). The study found that magnesium concentrations varied widely from 4.8 to 607.3 mg/l, with an average concentration of 96.3 mg/l. The diverse range of magnesium concentrations in the Sivakasi region underscores the intricate interplay of geological and anthropogenic factors. The identified sources, including Mg-containing minerals, silicate weathering, and industrial wastes, highlight the complexity of magnesium dynamics in groundwater (Potasznikand Szymczyk, 2015). The sodium concentration was from 29 to 394 mg/l with a mean value of 209.6 mg/l in the groundwater over the study area. Sodium dominance as the most concentrated cation in groundwater suggests various processes, including ion exchange, mineral dissolution, and potential anthropogenic inputs. The main source is from infiltration by irrigation fertilizers and interactions with rock mass (Gu *et al.,* 2018).

With a range of 2 to 32 mg/l, Table 3 revealed that the average K content was 10.4 mg/l. Sewage effluents, industrial wastes, and landfill leachates are a few examples of natural and artificial sources of chloride in water. With an average of 2473.15 mg/l, the chloride content in the area rangedfrom 141.80 to 2818.28 mg/l. The mean SO_4 value for the area is 363.6 mg/l, with values ranging from 64.7 to 800.6 mg/l. Groundwater in Sivakasi contained an average of 1.6 mg/l of fluoride, ranging from 0 to 2.6 mg/l. In the sample location, the hydrogen ion (H+) concentration averaged 7.66 mg/l and varied from 7.1 to 8.1 mg/l, both of which were below the permitted limit. The exceptable limit is for human consumption 6.5–8.5(WHO, 2017).

The average EC value in the studyarea was 2427.09 S/cm, ranging from 703 to 5288 S/cm (Table 3). The observed higher electrical conductivity in groundwater compared to surface water aligns with findings from Adimalla and Wu, (2019), Adimalla and Qian (2019a), and Ramya and Elango (2018). This phenomenon is indicative of the dissolved ion concentration in the water.The average EC values and their range in the study area, coupled with the higher electrical conductivity in groundwater compared to surface water, suggest that water-rock interactions play a significant role in influencing the chemical composition of the water (Adimalla and Qian,2019a;Ramya and Elango, 2018;Davis and DeWiest,1966; Freeze and Cherry,1979) proposed a TDS categorization system with multiple ranges to conclude the superiority of the area from which the water originates. The samples fell within the concern limits shown in (Table 4). WHO (2017) recommends a total dissolved solids (TDS) limit of 500-1500 mg/l for drinking purposes. With a mean of 1118.3 mg/l, the values in the table range from 323.94 to 2011.3 mg/l.

According to the weighted arithmetic index (Table 5), the water quality was very low and poor. The degree of groundwater quality in the study area for drinking water was assessed using the water quality index (WQI). The Weighted Arithmetic Index (WAI) in the study area ranged from 28 to 150, with an average of 83. Out of 32 samples, 37% were classified as harmful to drink, 25% were deemed very poor, 21% were deemed good, and 10% were deemed exceptional (Table 5). According to the calculated NPI (Table 6), the amount of dissolved ions in the groundwater determines how much TDS is present. TDS is the main parameterin the area under study. To identify pollutants in the groundwater of the research area, the NPI technique was used. With 91 % of the total, TDS appeared to be the greatest contaminant in groundwater, followed by Cl (85 %), S04 (73 %), Mg (64 %), Ca (49 %), Na (30 %), and K (15 %).

In Sivakasi, groundwater is the most crucial water source for agriculture. The Sivakasi groundwater suitability for irrigation was evaluated using the following criteria: sodium adsorption ratio (SAR), sodium %age (Na%), magnesium hazard ratio (MHR), and Kelly's ratio (KR). The SAR is important for crop yields because high salt concentrations can reduce soil permeability and harm soil structure. SAR values in the study area ranged from 4.2 to 20.3. According to (LA, 1972), 31% of the groundwater samples in the study area fall into the excellent category, while 69% fall into the good category for irrigation (Table 7).Most groundwater samples are categorized as either excellent or good, indicating a generally favorable condition for irrigation.

The EC values of study area ranged from 703 to 5288 μS/cm, with nearly 56% of the groundwater samples found suitable for irrigation and 37% deemed unsuitable. The Na% value of study area ranged from 24.8 to

Table 3. Summary of the computed hydrogeochemical parameters for the groundwater samples of Sivakasi

Parameters	Standards WHO (2017)	Minimum	Maximum	Average
p H (mg / l)	6.50-8.50	7.10	8.16	7.66
EC (µS/cm)	-	703	5288	2427.09
TDS (mg/l)	500	323.94	2011.30	1118.30
Ca (mg/l)	75	20	204	89.39
Mg (mg/l)	50	4.80	607.30	96.300
SO_4 (mg/l)	200	64.70	800.60	363.60
Na (mg/l)	200	29	394	209.6
K (mg/l)	12.0	2	32	10.40
Cl (mg/l)	200	141.80	2818.28	2473.15
HCO_3 (mg/l)	-	207.40	518.50	348.60
F (mg/l)	1.50	0	2.60	1.600

79.65. Over 34% of the samples were unfit for irrigation purpose, while 66 % were suitable, according to the Na % values suggested by (Karanth 1987; Wilcox 1948) (Table 7). In the study area, Magnesium Hazard Ratio (MHR) values vary from 13.04 to 70.83. About 47% of groundwater samples, according to MHR, are suitable for irrigation, while 53% of samples are notsuitable for irrigation (Table 7). A crucial statistic for assessing irrigation water qualitywas the ratio of Na concentrations to Ca2 and Mg2 concentrations (Kelly 1957). In the study area, KR values vary from 0.26 to 3.85. In the research area, 44 % of the groundwater samples were acceptable for irrigation while 56 % were not. The calculated non-carcinogenic health risk assessment HQ (maximum and minimum) results for infants, children, and adults are presented in Table 8. Infants had HQ values between 0.00 E + 00 and 1.69 E + 00, children between 0.00 E + 00 and 1.80 E + 00, and adults between 0.00 E + 00 and 1.88 E + 00.

Correlation Matrix

A correlation matrix was usedto establish correlations between the principal ions analyzed and to find a potential common ions source in the groundwater of the industrial zones of the Sivakasi area (Table: 9). All other elements, including Ca, Na, Mg, Cl, and salinity, have a positive relationship with EC. TDS has a tight bond with other ions. Ca and Mg have a favorable relationship with SO_4(Ekbal and Khan, 2022).

The level of fluoride was below the permissible limit in 31% of samples, above the permissible limit in 4% of samples, and within the optimum limit of 1 to 1.5 ppm in 65% of water samples over the study area. The fluoride concentration may be due to substantial interaction between water and rock formations, particularly on granitic terrain. This interaction significantly influences the fluoride concentration in groundwater and is considered geologically significant (Carrillo-Rivera*et al.,* 2002; Gizaw, 1996; Deshmukh, 1995). The increase in fluoride may cause chronic *fluorosis* exposure, dental fluorosis, skeletal fluorosis, and fetal fluorosis (Chen *et al.,* 1990; Dharmaratne,2015). The primary cause of fluoride content in ground water is natural contamination, but the dissolution process is still poorly understood (Saxena and Ahmed, 2001).In the Golestan area of northern Iran, the distribution of fluoride in the mother's breast milk was significantly influenced by the fluoride content of drinking water (Faraji *et al.,* 2014). In rural areas of Khaf City, Razavi Province, northeastern Iran, fluoride levels ranged from 0.11 to 3.59 ppm between 2009 and 2010 (Amouei, *et al.,* 2012).These studies underscore the geological significance of fluoride in groundwater and its potential health implications, necessitating ongoing research and monitoring efforts to

Table 4. Groundwater samples 'total dissolved solids (TDS) range

Range	Quality of water	%age of Samples	Reference
< 500	Suitable for Consumption	-	Davis and Dewiest (1966)
500 - 1000	Permissible for intake	28	
< 3000	Effective for water supply to agricultural land	50	
> 3000	Unsuitable for consumption and water supply to agricultural land	22	
< 1000	Fresh	31	Freeze and Cherry (1979)
1000-10000	Brackish	69	
10,000-100,0000	Saline	-	
>100,000	Brine	-	

Table. 5. Summary of the computed values for Weighted Arithmetic Index (WAI) and National sanitation foundation water quality index (NSFWQI)

WQI Method	Range	Quality	Total Number of Samples	%age Samples
	0-25	(Excellent)		10
	26-50	(Good)		21
Weighted Arithmetic Index	51-75	(Poor)	32	7
	76-100	(Very Poor)		25
	>100	(Unsuitable for Drinking)		37

Table 6. Showing the possible pollutants in the sampling locations according to NPI values

Pollutants	TDS	So4	Cl	Na	Ca	K	Mg
% of the pollutants	91	73	85	30	49	15	64

Table 7. Ground water classifications for irrigation based on theMagnesium Hazard Ratio (MHR), Sodium Absorption Ratio (SAR), Kelly's ratio (KR), sodium %age (Na%), electrical conductivity (EC)

Quality Parameters	Range	Classification	Sample Range	%age of Samples
MHR	>50	Unsuitable for irrigation	13.04 - 70.83	53
	<50	Suitable for irrigation		47
SAR	<10	Excellent	4.23- 20.6	69
	10-18	Good		31
	18-26	Permissible		0
	>26	Unsuitable		0
KR	<1	Suitable for irrigation	0.26-3.85	44
	>1	Unsuitable for irrigation		56
Na%	<20	Excellent for irrigation	24.8 - 79.65	0
	20-40	Good for irrigation		0
	40-60	Permissible for irrigation		66
	60-80	Doubtful for irrigation		34
	>80	Unsuitable for irrigation		0
Na%	>60	Unsuitable for irrigation	24.8 - 79.65	34
	<60	suitable for irrigation		66
Ec μS/cm	<250	Excellent	703 - 5288	0
	250-750	Good		7
	750-2250	Permissible		56
	>2250	Unsuitable		37

comprehend better and manage this environmental factor. The study attributes that adults are exposed to increased non-carcinogenic risk in the research area than babies and children (Fig.2). In Fig. 2,3,HQ values showed greater than one nearly 43% of adult samples, 36% of child samples, and 21% of infant samples. As a result of the calculated health risk assessment for fluoride, the ground water has become contaminated with fluoride. This is in alignment with the previous studies done by (Sunitha *et al*.,2022,Duvva*et al.,* 2022; Dharmaratne,2015), where they have reported adults are more vulnerable than newborn babies .It is because adults have longer exposure durations than infants and children (Sunitha *et al*.,2022;Azhdarpoor *et al.,* 2019). The section underscored the distribution of fluoride levels in water samples, the associated non-carcinogenic risks, and the importance of considering exposure duration. The alignment with previous studies adds validity to the findings, emphasizing the need for ongoing research and intervention strategies to manage and mitigate potential health risks associated with fluoride in the groundwater resources of thestudy area.

It is suggested that the concentration of fluoride and other significant ions in the groundwater of Sivakasi be evaluatedto comprehend the non-carcinogenic hazards faced by the local population, specifically adults, and to

Table 8. Maximum and Minimum values of HQ for fluoride in groundwater in Sivakasi area

Element	Range	Infants	Child	Adult
Fluoride	(Maximum)	1.69 E+00	1.80 E+00	1.88 E+00
	(Minimum)	0.00 E+00	0.00 E+00	0.00 E+00

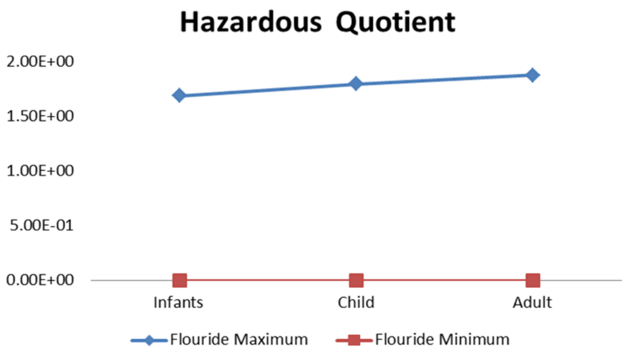

Fig. 2. *Fluoride contamination from study area*

determine whether the water is suitable for drinking and agricultural use.The potential health hazards associated with elevated fluoride levels particularly focusing on the heightened vulnerability of adults should be emphasized. This information is vital to reduce the impact of disasters and efficiently distribute resources. The significance of ensuring the protection of reliable water sources and using robust water management strategies in semiarid areas should be highlighted to tackle concerns related to the quality of groundwater. The study's distinctiveness is underscored by its specific emphasis on health risks associated with elevated fluoride levels, particularly posing a concern for adults. This novel perspective makes the findings essential for disaster mitigation efforts in the region.

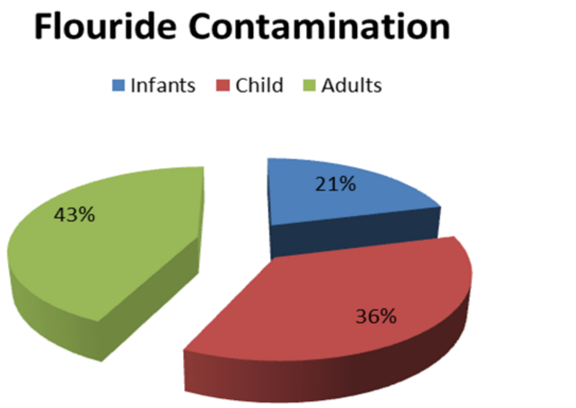

Fig 3.*Fluoride contamination in groundwater for adults, children and infants.*

Conclusion

This study conducted a thorough analysis of hydrogeochemical parameters in order to assess the quality of groundwater. The findings indicated that the dominant cations and anions in the groundwater followed the order of Cl > SO4 > HCO3 > Na > Mg > Ca > K. When compared to the WHO 2017 guidelines, most of the samples exhibited levels that were below the highest permitted limits. The pH fluctuations indicated that the groundwater quality ranged from mildly alkaline to moderately alkaline. The calculated indices classified the water as moderate to poor for drinking and agricultural purposes. The main objective was to evaluate the levels of fluoride in the groundwater of Sivakasi and the potential health hazards it poses to newborns, children, and adults. The fluoride concentrations varied between 0 and 2.6 mg/l, averaging 1.6 mg/l. Health risk assessments revealed that adults were subjected to greater non-carcinogenic risks in comparison to babies and

Table 9. Sivakasi area's primary ion correlation matrix

	pH	Ec	T D S	Salinity	Na	K	CO3	Cl	SO4	HCO3	Ca	Mg
pH	1											
Ec	-0.2790	1										
TDS	-0.2790	1	1									
Salinity	-0.2770	0.9990**	0.9990**	1								
Na	-0.1370	0.7480*	0.7480	0.7480*	1							
K	-0.0180	0.1370	0.1370	0.1300	0.0640	1						
CO3	0.17380	-0.0240	-0.0240	-0.0280	0.0950	-0.1360	1					
Cl	-0.3470	0.9610**	0.9610**	0.9590**	0.6180	0.1730	-0.0560	1				
SO4	0.09930	0.5040	0.5040*	0.5100*	0.7590*	0.01900	0.0860	0.2990	1			
HCO3	-0.0640	0.0270	0.0270	0.0370	0.2940	-0.0680	-0.1000	-0.0900	0.27300	1		
Ca	-0.3360	0.86250**	0.8620**	0.8610**	0.4260	0.1370	-0.1810	0.8890**	0.2560	-0.1410	1	
Mg	-0.1450	0.6580*	0.6580*	0.6650*	0.3480	0.1180	-0.0820	0.6020	0.5120*	-0.0040	0.7330*	1

children. The values of non-carcinogenic health risk assessment HQ (maximum and minimum) for newborns, children, and adults ranged from 0.00E+00 to 1.88E+00, highlighting the potential dangers. The study definitively demonstrated that individuals residing in the study area were exposed to non-carcinogenic hazards due to fluoride contamination in the groundwater. Adults were exposed to increased non-carcinogenic risk in the research area than babies and children. This highlights the pressing necessity for government intervention to increase public knowledge and guarantee the availability of water without fluoride, thereby addressing the population's health issues.

Conflict of interests

The authors declare that they have no conflict of interest.

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