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Hydrogeochemical analysis and quality assessment of groundwater in Hothpeth and surrounding villages, Shahapur Taluka, Yadgir District, Karnataka State, India

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Abstract

Water is the precious natural resource. Water takes up most of the world's surface area, but the majority of the water is not drinkable, and that's why water is a limited resource. Therefore, care must be exercised while consuming this precious limited resource. Sources of water should be inspected at regular intervals to assess its overall quality. Besides being an indication of ecological deterioration, contaminated water bodies are harmful to the environment. Poor water quality in industries can have grave implications. The condition of water significantly influences both environmental health and economic development. The analysis of the quality of water is therefore required before it is being utilized for any intent. Water quality analysis entails a range of standard procedures, such as sample collection, preservation, and analysis guidelines. This study focuses on identifying the key hydrogeochemical processes affecting groundwater quality and evaluating its appropriateness for household and agricultural applications in the Shahapur Taluka, Yadgir District villages. This study stems from growing concerns about water contamination in the region, particularly in areas situated near the interface of varying lithological formation. A total of 22 groundwater samples collected from the region revealed elevated levels of fluoride, total dissolved solids (TDS), total alkalinity (TA), total hardness (TH) due to calcium and magnesium, chloride, and sodium. The relative ion concentrations in aquifers are as given below:

Na > Cl > Mg > Ca > F > NO^3

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Introduction

Water is a vital resource since it possesses several unique qualities. We all use water to prepare, clean, cultivate, drink, and wash; therefore, it's our most valuable endurance resource. The fact that industry requires significantly more water to generate power, make materials, to transport people and goods is one factor contributing to the everyday consumption. Increased demand for water is being caused by urban sprawl, growing populations, and expanding economic activity. As quantities decrease and the quality worsens, surface water and groundwater become over-exploited, which puts many resources in danger.[1-3] According to Witek and Jarosiewicz, surface water quality degradation is becoming a major problem in many nations, and resource conservation policies place a high priority on water quality monitoring.[4] As a result, the rising nations are working harder to assess the quality of surface waters and rivers.[5,6] A survey of literature reveals that very massive work has been made pertaining to surface and subsurface water pollution and related aspects in India and around the world with specific reference to geological conditions of the area. Some important studies are those of Lavanya,[7,8] who have discussed geological influences on water quality and how it affects the life of organisms. J.K. Fawell, discussed the impact of drought on groundwater quality.[9] Kulandaivel carried out research on the assessment of ground-water resources and the analysis of hydrochemical properties of groundwater in a specific region, which has significant applications.[10] Senthilkumar *et al*., Monitoring and ensuring the safety of potable water supplies,1[1,12] K Naika *et al*., studied fluoride pollution in groundwater in Yadgir taluk,[13] Vineeth Ajith, studied about comprehensive approach to evaluating the quality of drinking water.[14] Despite various studies on groundwater quality in Karnataka, there is a significant lack of localized, detailed investigations in rural pockets like Hothpeth and its surrounding villages. This study attempts to provide current, site-specific physico-chemical parameters and the study provides insights into the geochemical mechanisms governing fluoride distribution in the groundwater of the region. This study is primarily driven by the need to assess groundwater quality, as it represents the main trace of drinking water in rural communities like Hothpeth and neighboring villages in Shahapur Taluka. With increasing reports of water-borne health issues and the region's vulnerability to geogenic contamination, particularly fluoride,[13] it becomes essential to understand the hydrogeochemical characteristics influencing groundwater quality. The objectives of this study are to analyze the physico-chemical characteristics of groundwater, map their spatial distribution, and assess the suitability of groundwater for drinking purposes and household use through established water quality indices.

Materials and Methods

Water samples were obtained during the post-monsoon period from various locations, including Hothpeth, Maktapur, Mudabal, Maratagi, Ganwar, Kodamanahalli, and neighboring villages, with the objective of assessing the quality and usability of both surface and groundwater resources. Twenty-two borewell water samples were collected in total and open wells in eight villages located in the northern part of Shahapur Taluka, near Hothpeth. These villages are part of a fluoride-endemic belt and have experienced water quality issues, including several deaths attributed to poor water quality. The water samples were obtained from borewells and open wells equipped with either submersible pumps or, less commonly hand pumps, all of which are actively used for supplying drinking water to the local communities.

Fresh groundwater samples were drawn into pre-cleaned containers after flushing the borewells for 3–5 minutes to remove stagnant water and obtain representative inflow samples. Parameters such as pH, Total Dissolved Solids (TDS), and Electrical Conductivity (EC) were measured using the Water Analyzer Model 371. For chemical analysis, Total Hardness (TH), Total Alkalinity (TA), along with calcium and magnesium concentrations, were determined using EDTA titration and other conventional titrimetric methods with a standard titration setup. Magnesium concentrations were specifically calculated using the calculation technique. Fluoride, nitrate, and chloride levels were measured using a spectrophotometer and titration assembly equipment, following the Argento metric, Alizarin, and phenol sulphonic acid methods, respectively. All methods were applied and validated at the Agricultural University's research center in Bhemarayana Gudi (B Gudi), Shahapur Taluka, Yadgir District.

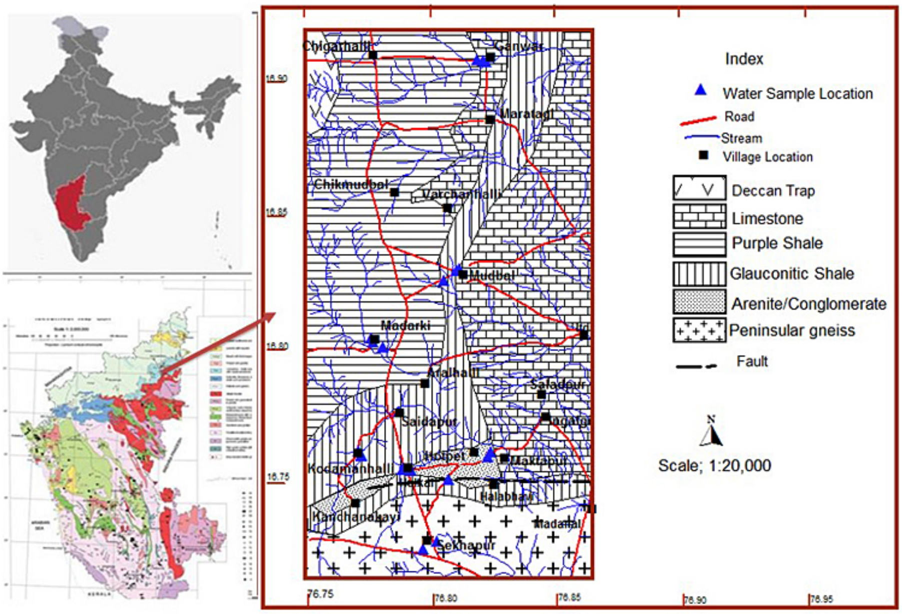

Fig. 1. Location map

The study area is located in the Yadgir district of Karnataka, India, to the north of Shahapur. The study focuses on an area of approximately 75 km², predominantly within Shahapur Taluk, and is bordered by the Bhima and Krishna rivers (Figure 1). The point where these two rivers meet, referred to as 'Sangam,' it is located in the southeastern region of the study area. The research region, covered by toposheet numbers E43W13 and E43W14, features a maximum elevation of approximately 580 meters above mean sea level (MSL) in the northern part and a minimum elevation of 340 meters MSL in the southeast.

Between 2001 and 2010, the district recorded an average yearly rainfall of 699 mm, whereas in 2021, the actual rainfall dropped to 633 mm. Over 77% of the annual rainfall in the region generally takes place during the Southwest monsoon period, which lasts from June to September. The coldest month in the region is December, with average high and low temperatures of approximately 25°C and 15°C, respectively. The area is characterized by a semi-arid climate, with summer temperatures often soaring to a maximum of around 45°C. The study area is primarily agricultural, with the main crops being cotton, groundnuts, pulses, jowar, and paddy. All season connecting roads and sampling locations are shown in the location map.15

Hydrogeology

In the southern part of the study region, the predominant exposed rock formation is the Peninsular Gneiss, which forms the underlying basement of the basin. Limestone formations are more commonly found in the central areas of the region, interbedded with purple and glauconitic shales, and a conglomerate layer at the base, indicating an unconformable contact with underlying granite. The northwestern part of the area is dominated by the Deccan Traps. The area also exhibits a geological boundary where sedimentary rocks meet granite, shaped by the east–west trending Gogi-Kurlagere reverse fault, which reveals formations such as limestone, grey and purple shales, and rocks belonging to the Bhima basin.

This region falls within the lower Bhima basin, part of the Sedam subgroup, and specifically within the Shahabad Formation, which is characterized by vertically alternating layers of limestone and shale. The sediments of the Bhima Basin overlie the ancient Precambrian granite-greenstone terrain, positioned along the northeastern margin of the Dharwar Craton.[16] Foote (2001) historically classified the Bhima basin into two stratigraphic divisions: the Upper and Lower Bhima Series, based on distinct sedimentary units.[17] These sequences include repeated layers of limestone and shale, as well as formations of conglomerate and sandstone. Granite outcrops are uncommon due to widespread agricultural activity in the region. Nonetheless, the granitic rocks within the Bhima basin are notable for their elevated uranium content, which is mobilized from accessory minerals and accumulates along fault zones under the influence of hydrothermal processes. The northwestern part of the sedimentary sequence is capped by Deccan Trap formations, which date back to the Upper Cretaceous to Eocene epochs (refer to Figure 2).

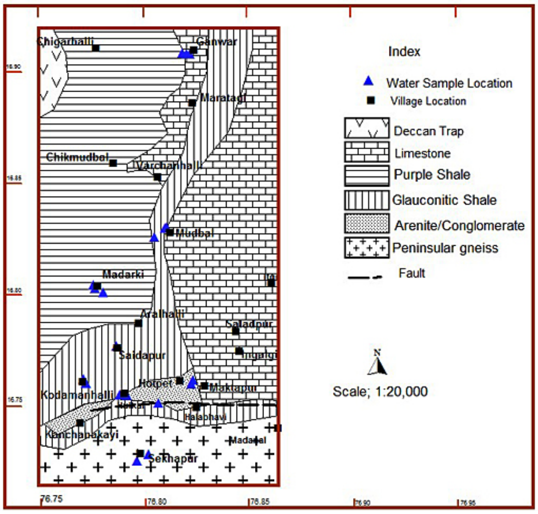

Fig. 2: Geological representation of the study region.

In the majority of locations, the basement rocks are overlain by a shallow cover of topsoil—primarily lateritic.[15] Groundwater is primarily found in jointed, weathered, and fractured zones of the strata. Rainfall serves as the primary source of groundwater recharge, with additional contributions from canal seepage and irrigation return flow. From a hydrogeological perspective, the sedimentary terrain in the northwest is characterized by a complex subsurface layering, while in the central and southeastern parts, topsoil directly overlies basement rocks composed of Peninsular Gneiss and granite.

Drainage System

Water quality refers to the chemical, physical, and biological characteristics of water,[18] which collectively determine its appropriateness for purposes like drinking, recreation, and supporting aquatic ecosystems.[19] These factors are further influenced by stream flow, which affects both water quality and quantity.[20]

The study area exhibits a dendritic drainage pattern, with most streams flowing eastward towards the Bhima River, located about 20Km away. The morphology of these streams transitions from a plain to a gentle slope as they flow from west to east. According to Ramaling Natikar *et al.*, the shape and size of streams are influenced by the geological formations that determine their morphometry.[21] In the southern portion of the study area, a small creek flows from north to south before curving eastward. A reduction in stream flow can negatively impact the various uses of a water body, including its ecological health and suitability for human activities.[20,22]

Hydrochemical Analysis

One of the most important initial steps in fixing issues with domestic water quality is locating a water analysis from a testing facility. Prior to testing, it might have been concerned about the safety of the water used in the domiciliary. A correctly interpreted water analysis report is crucial for determining the exact cause of contamination issues and for determining what kind of remedial action to take.

Regarding public water systems, many established criteria are legally enforceable and based on health concerns, while others are determined by nuisance factors (taste, odor, discoloration, etc). 22 samples of groundwater and surface water from 8 distinct sampling locations (Hothpeth, Hulkal, Kodamanalli, Saidapur, Maddaraki, Mudbal, Ganwar, and B. Gudi) were examined for different physico-chemical properties. Table 1 provides a summary of the outcomes.

Climate

After January, April is the hottest month in the research region due to the quick increase in temperature. Four seasons distinguish the year's climate. The Southwest monsoon typically prevails from June to September, succeeded by the post-monsoon period, which spans from October to November, April to May is the hot season.

Table 1: Physico chemical parameter ranges in the study area.

Physio-chemical Parameter		Villages of the Study Area (Shahapur Taluka, Yadgir District)							
		Hoth -peth	Hulkal	Kodam -anahalli	Saidapur	Maddaraki	Mudbal	Ganwar	B Gudi
pH	Min.	6.85	7.01	7.53	7.28	6.28	6.98	7.12	6.27
	Max.	7.13	7.35	7.72		7.1	7.48	8.98	7.19
Electrical Conductivity (µS/cm)	Min.	876	1730	931	2150	925	1100	1500	1410
	Max.	1470	2430	3350		1800	2400	10000	2270
TDS (ppm)	Min.	462	910	462	1140	510	610	860	760
	Max.	770	1280	1820		950	1310	5460	1260
Total Alkalinity (ppm)	Min.	404	456	428	652	440	608	652	644
	Max.	600	684	736		532	840	1120	684
Total Hardness (ppm)	Min.	515	495	415	605	385	455	490	575
	Max.	575	610	705		615	550	1005	995
Calcium (ppm)	Min.	44.04	42.04	24.02	88.09	8.01	18.02	44.04	78.08
	Max.	78.08	114.1	118.1		58.06	30.03	154.15	138.1
Sodium (ppm)	Min.	144.04	142.04	124.02	186.09	140.02	180.02	166.07	175.08
	Max.	174.08	1104.11	1120.12		1008.01	1114.01	1150.15	1130.1
Magnesium (ppm)	Min.	78.26	64.84	76.92	91.26	59.23	99.49	77.29	90.3
	Max.	104.8	93.88	96.44		144.94	116.7	146.6	154
Chloride (ppm)	Min.	110.63	164.5	195.7	249.62	147.5	167.4	309	343.2
	Max.	138.99	232.6	280.8		180.8	354.6	428	451
Fluoride (ppm)	Min.	3	2.1	2.15	3.15	3.75	2.85	2.85	2.18
	Max.	3.5	3.26	2.75		3.85	3.82	3.18	3.26
Nitrate (ppm)	Min.	1.1	0.73	0.45	4.03	2.25	1.18	0.52	0.55
	Max.	2.05	3.17	0.56		8.42	6.36	5.9	0.64

Results

Temperature of Water

Although the study area experiences mostly hot weather, Water temperature significantly affects the chemical and biochemical dynamics of aquatic systems, with observed values generally ranging from 25°C to 45°C. Because of the high temperature, clear sky, and low water level, the summertime water temperature was high.[23]

pH

pH represents the measure of hydrogen ion concentration in water.[24] A pH value below 7 signifies an acidic condition, while values above 7 extending up to 14 represent alkaline conditions. pH of the water systems affects most biological, chemical, and geological reactions. According to WHO guidelines, the acceptable pH range for drinking water lies between 6.5 and 8.5.[25]

In the current study, the pH values of the water samples ranged from 6.27 to 8.98.The pH values in the Bheemarayana Gudi (B Gudi) and Hothpeth area lower than the allowable limits, at 6.27 and 6.28, respectively.

Total Dissolved Solids (TDS)

The behavior of groundwater's salinity is shown by total dissolved solids. Although it is not deemed idea for drinking water sources, water with more than 500ppm of TDS is permitted in certain situations. TDS levels Within the study region, values ranged from 590 ppm and 5460 ppm.

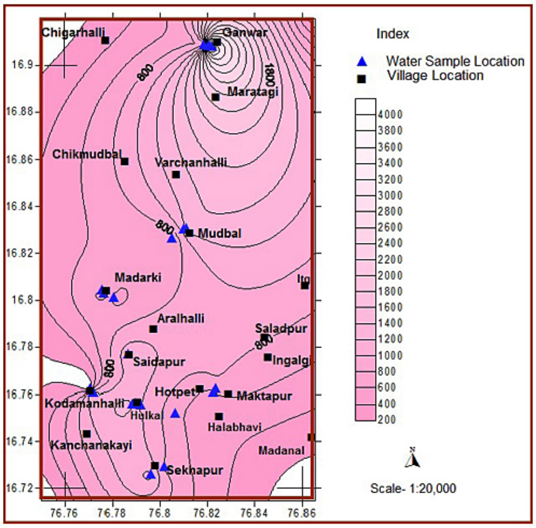

Fig. 3: Spatial variation of total dissolved solids within the surveyed region.

Electrical Conductivity (EC)

Water's capacity to conduct electricity is dependent on the amount of salts and inorganic compounds it contains. It also changes depending on the temperature of the water. The content of salt and inorganic compounds in the water has altered because of changes in electro conductivity. Inorganic substances that are dissolved in water and are mostly found in ionized form are measured using the electrochemical conductivity (EC) levels vary between 876 and 10,000 µS/cm.

Higher EC values were recorded in several places, including Ganwar (10,000 micro-µS /cm), B Gudi (1260 micro µS /cm), Hulkal (2430 micro µS /cm), Mudbal (2400 micro µS /cm), and Kodamanahalli (3350 micro µS /cm).

Table 2: Groundwater classification based on TDS after Davis and Dewiest (31,23)

TDS (ppm)	Water type	Number of Samples	%
<500	Desirable for drinking	1	4.54
500-1000	Permissible for Drinking	11	50
<3000	Useful for Irrigation	8	36.36
>3000	Unfit for Drinking and Irrigation	2	9.1

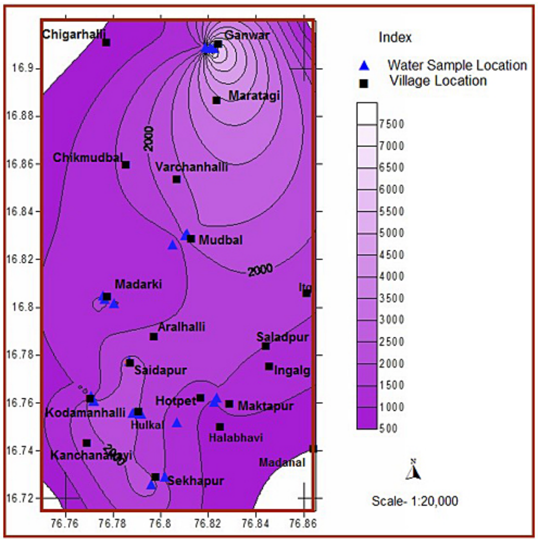

Fig. 4: Spatial patterns of electrical conductivity within the surveyed area.

These EC values and their spatial distribution throughout the research region are probably visually represented by the figure 4.

Total Hardness (TH)

Hard water tends to increase the boiling point of water and reduces the formation of soap lather. The amount of calcium or magnesium salt, or both, determines how hard the water is. The hardness displayed values are in the range of 385 ppm to 1005 ppm. Figure 5 illustrates the spatial variation in total hardness. When groundwater contains more than 300 ppm of $CaCO_3$, it is regarded as extremely hard. The WHO worldwide rules state that the most acceptable limit for TH in drinking water is 100 ppm, while the maximum allowable amount is 500 ppm. Each sample contains above the uppermost permissible limits (Table 4).

Table 3: Surface and Groundwater samples of the study area surpassed the permissible limits recommended by the WHO for drinking purposes.

Parameters	WHO International Standard (2011)		Number of Samples Exceeding Permissible Limits	Percentage of Samples Exceeding Permissible Limits (%)
	Desired Limit	Permissible Limit		
pH	6.5-8.5	8.5	1	4.54
TH (ppm)	200	500	12	54.54
Na (ppm)	-	200	8	36.36
Ca (ppm)	100	200	8	36.36
Cl (ppm)	-	250	9	40.90
F (ppm)	0.5	1.5	22	100
TDS (ppm)	500	1000	11	50

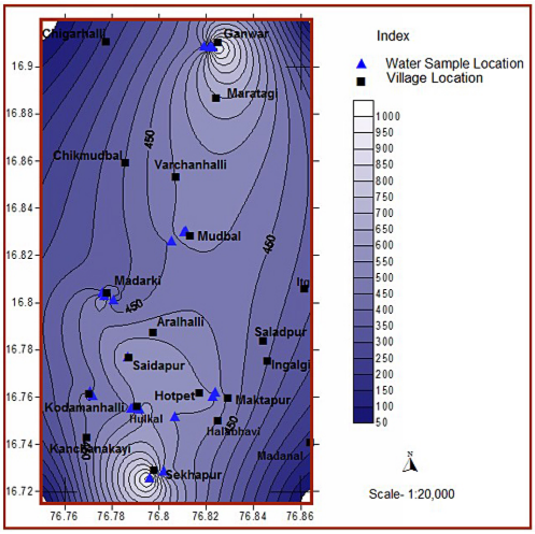

Fig. 5: Total Hardness distribution in the study area.

Flouride (F)

Fluoride can be found in nature as phosphorite crystals, rock phosphate, and fluorspar (fluorite). Fluoride levels in some black shales and organic-rich sediments may be higher than average. Because these rocks contain organic content, weathering processes may mobilize fluoride more easily, resulting in higher quantities in groundwater.[7,13,26] Some of the sampling stations in this study had fluoride concentrations above the WHO's acceptable limit of 1.5 ppm.[25] Fluoride in these water samples may originate from rock weathering, the use of phosphatic fertilizers in agriculture, or sewage sludge.

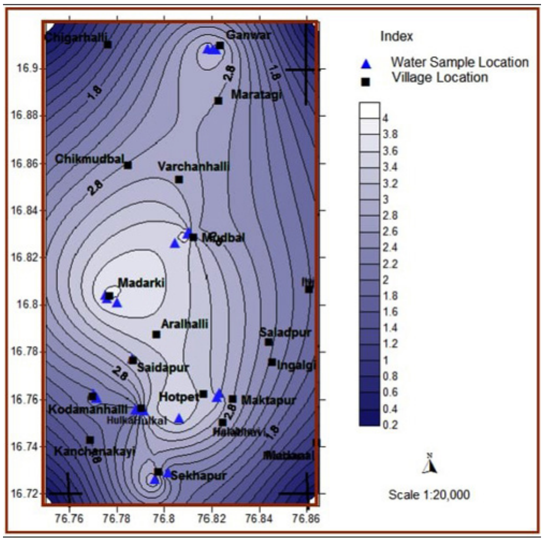

Fig. 6: Geographical distribution of fluoride across the study area.

During the study period, concentrations varied between 2.1 ppm and 3.85 ppm, as illustrated in Figure 6, all of which are more than the WHO's acceptable limit of 1.0 ppm,[26] according to this study. Higher levels of fluoride are found near Maddaraki (3.85 ppm), Mudbal (3.82 ppm), Hothpeth (3.5 ppm), B. Gudi (3.26 ppm), Ganwar (3.16 ppm), and Hulkal.

Table 4: Comparison of Physico-chemical parameters of Open well and Borewell samples of the study area.

Para -meter	Hothpeth		Hulkal		Kodama -nahalli		Saidapur	Maddaraki		Mudbal		Ganwar		B Gudi
	BW	OW	BW	OW	BW	OW	OW	BW	OW	BW	OW	BW	OW	BW
	Average		Average		Average		Average	Average		Average		Average		Average
pH	6.9	7.1	7.2	7.2	7.7	7.6	7.3	6.8	6.3	7.1	7.5	7.4	9	6.7
EC	1053	1470	1730	2120	931	2725	2150	1630	925	1750	1960	3840	10000	1840
TDS	556	770	910	1106.7	590	1425	1140	865	510	960	1070	2100	5460	1010
TA	464	600	456	657.3	428	730	652	522	440	730	608	718	1120	785
TH	560	515	505	556.7	415	572.5	605	505	385	485	550	755	490	785
Ca	61.1	74.1	66.1	84.8	38	71.1	88.1	33	20	16	30	99.1	66.1	108.1
Na	157.1	174.1	166.1	481.1	139	622.1	186.1	581	140	647	230	1097.1	166.1	652.6
Mg	97.6	78.3	81	81.6	76.9	94.2	91.3	102.1	81.1	108.1	115	120.8	77.3	122.4
Cl	131.9	110.7	164.5	219.4	195.7	266.6	249.6	238.3	147.5	232.6	354.6	368.8	348.9	397.1
F	3.4	3	2.3	2.7	2.2	2.5	3.2	3.8	3.8	3.2	3.8	3.2	2.9	2.7
NO_3	1.6	1.7	2.2	1.8	0.5	0.6	4	5.6	2.3	1.6	6.4	3.2	3	0.6

Total Alkalinity (TA)

It is a measure of amount of bicarbonate, carbonate or hydroxide in water. The recommended range of drinking water is 20 – 200 ppm as $CaCO_3$, local geology is the biggest contributor of alkalinity in water. Water quality and its effects on aquatic life are greatly influenced by alkalinity, which buffers the pH level of the water. A steady pH or water with a high alkalinity makes their living conditions ideal. Since carbonate rocks (CaCO3 or limestone) are the primary source of alkaline water, alkalinity and water hardness are closely related.

Alkalinity levels in the study area were found to range between 400 ppm and 1120 ppm, as depicted in Figure 7. The high alkalinity values observed in the following areas: B Gudi (684 ppm), Kodamanahalli (736 ppm), Maddaraki (532 ppm), Hothpeth (600 ppm), Ganwar (1120 ppm).

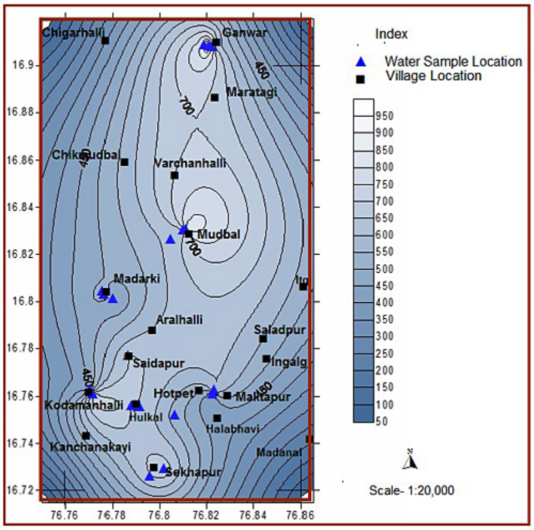

Fig. 7: Spatial distribution of total alkalinity across the study area.

Sodium

In the study area, sodium content varies. The values varied significantly, ranging from a minimum of 124.02 ppm in Kodamanahalli to a maximum of 1150.15 ppm in Ganwar.

Calcium

Calcium concentrations in water samples from the study area range from a minimum of 8.01 ppm in Maddaraki to a maximum of 154.15 ppm in Ganwar. The elevated calcium levels in the Ganwar region are likely due to the presence of limestone formations.

Magnesium

The magnesium concentration ranges from 59.23ppm (Maddaraki) to 146.6ppm (Ganwar) which is once again the geological influence of Dolomitic limestone in the study area.

Table 5: Correlation matrix

	pH	EC	TDS	TA	TH	Ca	Mg	Cl	F	NO_3
pH	1									
EC	0.67	1								
TDS	0.64	1.00	1							
TA	0.66	0.74	0.75	1						
TH	-0.07	0.30	0.32	0.09	1					
Ca	0.08	0.33	0.33	0.09	0.77	1				
Mg	-0.20	0.13	0.15	0.05	0.74	0.15	1			
Cl	0.25	0.52	0.53	0.53	0.68	0.41	0.63	1		
F	-0.28	-0.10	-0.06	-0.22	0.10	-0.11	0.27	0.00	1	
NO_3	0.00	-0.03	0.00	0.04	-0.17	-0.45	0.21	0.11	0.44	1

Chloride

Although chloride is a Earth's crust minor component of the, it is a major dissolved constituent in natural waters. In the study area, chloride concentrations range from 110.63 ppm at Hothpeth to 451 ppm at B. Gudi.

Nitrate

Nitrate concentrations range from as low as 0.45 ppm at Kodamanahalli to a maximum of 8.42 ppm at Maddaraki. All the samples are falling within safe limit as mandated by WHO.

Discussion

The observed analytical data shows the pH ranges from 6.27 (B Gudi) to 8.98 (Ganwar). The Ganwar area is comprising of limestone. The limestone present in the Ganwar region significantly influences the area's pH, contributing to its high alkalinity. The sampling points revealed that Ganwar village had a higher TDS of 5460 ppm and Kodamanahalli had lower TDS values of 590ppm (Figure 3). According to the TDS-based classification, only 54% of the water samples fall within the acceptable range for drinking purposes (Table 2). All these samples comprised high carbonate, bicarbonate, chloride, calcium, magnesium,sodium, and potassium cations water with high TDS. Regions underlain by limestone possess a greater range of TDS, consistent with the observation that alkaline rocks give more solids for dissolution and consequently conditions other than lithology dictate TDS content.

Electrical conductivity (EC) values range from 876 μS/cm to 10,000 μS/cm. Higher EC values appear in the areas where several geological formations congregate, sandstone, and/or limestone contact. TDS is positively co related with EC and (Table5). The analysis of calcium and sodium levels in the study area indicates that 36.36% of the water samples exceed the permissible limits (Table 3).

The disintegration and release of the chemicals into the water can be impacted by the presence of limestone, shale, conglomerate, or sandstone, which can change the EC of the water. The variations are described by Scatena,[27] have some of the controlling factors on the mineral content and, therefore, the electrical conductivity of the water and land use is one of the most important variables, industrial and agricultural operations, and mineral concentrations. Water with high electrical conductivity can lead to corrosion of metal components in appliances such as boilers, as well as household fixtures like faucets and water heaters. Excessive conductivity also eliminates species of plants that provide habitat and serve as food.[28-34]

These were found to have high Total Hardness values in the areas that are: B Gudi (995 ppm), Kodamanahalli (705 ppm), Maddaraki (815 ppm), Hothpeth (610 ppm), Ganwar (1005 ppm), and others (Figure 5). Calcium in groundwater in the research area is also conforming to the pattern of TH, having a positive relationship with calcium concentration and TH. Calcium carbonate-rich rocks such as limestone can increase water hardness by releasing calcium ions upon dissolution. In the study area, more than 54% of the water samples were found to be unsuitable for drinking based on WHO guidelines.

All Groundwater samples in the field area contain high levels of fluoride and fluoride content varies between and among various lithounits.The varying lithounits shales limestone and gneisses carry the high level of F > 1.5 mg/l. Groundwaters containing high levels of fluoride are perhaps because of their highly schistose nature permitting easy and fast dissolution of the source minerals. Significant fluoride concentrations can be found in sedimentary rocks, dolomite, and limestone, particularly in regions where these minerals are common. The total alkalinity of the area ranges from 400ppm to 1120ppm. Ganwar area is showing highest TA as it is comprised of limestone which releases carbonates and bicarbonates to the groundwater by dissolution. Elevated pH levels are attributed to increased alkalinity and bicarbonate concentrations in the area's groundwater. The higher sodium, magnesium, and calcium level in the Ganwar area can be attributed to limestone lithology. Nitrate levels in all the analyzed samples fall within the permissible limits set by the WHO.

Maddaraki, Mudbal, and Ganwar are mainly agricultural regions, where nitrate in groundwater likely results from sewage, fertilizers, and animal waste. Positive correlations among pH, EC, TDS, and TA suggest chloride contributes to groundwater hardness. Cation and anion levels are influenced by geology, soil, and arid climate.

Conclusion

The research focused on assessing the chemical composition and quality of groundwater in Hothpeth and the surrounding villages located in Shahapur Taluka, within the Yadgir District. This region falls under the Bhima geological formation, characterized by limestone, shale layers, Closepet granite, Deccan trap rocks, and Peninsular Gneissic Complex (PGC), exhibiting a dendritic drainage structure. Groundwater samples from the area were systematically collected and subjected to analysis for a range of physicochemical indicators, with a particular emphasis on fluoride concentration. The results indicated elevated values of Total Dissolved Solids (TDS), Electrical Conductivity (EC), Total Hardness (TH), Total Alkalinity (TA), Calcium (Ca), Chloride (Cl), Fluoride (F), and Sodium (Na). Notably, fluoride levels surpassed the World Health Organization's permissible limit of 1.5 ppm (2011) in every sample, establishing it as a significant geogenic pollutant. Among the detected ions, sodium was most prevalent, followed by chloride, magnesium, calcium, fluoride, and nitrate, in that order. The excessive fluoride content is likely due to the leaching of fluoride-rich minerals found in the local rock formations—particularly glauconitic shale and Closepet granite—facilitated by the naturally alkaline groundwater conditions. Settlements situated near geological contact zones—such as Hothpeth, Maktapur, Mudabal, Maratagi, Ganwar, and Kodamanahalli—are particularly susceptible to contamination. The study underscores the critical role of local geology in shaping groundwater quality and stresses the need for routine monitoring of fluoride concentrations to safeguard public health.

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Data Availability Statement
The water samples have been collected from the study area and physico-chemical parameters have been analyzed in the laboratory.

Ethics Statement
The study was conducted in accordance with the ethical standards ensuring transparency and respect for all involved.

Informed Consent Statement
Participants provide informed consent, acknowledging the study's purpose, procedures, risks, and their right to withdraw at any time.

Permission to Reproduce Material from other Sources
Not Applicable

Author Contributions
- **Ramalinga Natikar:** wrote whole paper,
- **Lavanya Hegde:** review and editing.
- **Aloka Timmappa Hegde:** prepared map, edited and reviewed.

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