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EVALUATION OF GROUNDWATER QUALITY AND PROBABILISTIC HEALTH RISKS FROM NITRATE & FLUORIDE CONTAMINATION IN WATERSHED REGION, TELANGANA STATE, INDIA

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Abstract

The hydrogeochemical regulating variables for the high rate of groundwater defilement in a semi-arid region's shallow hard rock aquifer have been collected. In the 2018 year, a total of forty groundwater samples were tested throughout the pre- and post-monsoon seasons. The south-western, northern, and central regions of the region show a spatial dispersion of nitrate values. In terms of NO_3^-, approximately 53 percent and 68 percent of groundwater samples surpassed the 45 mg/l acceptable limit. High fluoride readings were found in areas of the region's north-eastern, north-western, south-eastern, and south-western regions. Fluoride concentrations have been found in the research area, with between 50 and 60 percent of the water samples exceeding the acceptable 1.5 mg/l level in drinking water requirements. The piper trilinear revealed that the primary groundwater types were Na-Ca-Cl and mixed Ca-Mg-Cl. The majority of the area is rock dominant filed, according to Gibb's plot. The study region's water chemistry is dominated by weathering of feldspar minerals and cation exchange reactions, according to statistical analysis. Groundwater chemistry is influenced by weathering of silicate group minerals and cation exchange processes, according to factor analysis. In addition, the Hazard Quotient (HQ) and Total Hazard Index (THI) for nitrate and fluoride for adults and children were determined. In both children and adults, the hazard quotients for fluoride and nitrate groundwater samples above the allowed limit for the non-carcinogenic danger of 1.0, indicating that children are at a higher risk than adults.

Keywords: Spatial distribution, Piper, Gibb's plot and Hazard quotient

1. Introduction

The essential for water for human health, increase population, and economic expansion is exaggerated. A safe water supply for human health is very important of various sectors. The groundwater issues, the pollutant of water and exciting the environment within the worldwide struggle the problem with the Indian scenario (Subba Rao et al. 2019). The groundwater resources were engineered totally on the notion of accessible renewable resources. These days groundwater was extremely prime vital sources to balance the difficulties and preserve groundwater property to satisfy the human and environmental needs (Sakram et al. 2020). Nonappearance of aquatic, in dried and semi-arid parched due to the absence of water, in parched and semi-arid regions, specifically; one-third of the globe population depends upon groundwater for his or her day by day desires, particularly for drinking uses (Laxman Kumar et al. 2019; USEPA 2006). Due to alternation in common natural, human exercises, rural and mechanical exercises, groundwater quality is bit by bit deteriorating, causing water need crisis and various biological issues (Satyanarayana et al. 2017; Zhang et al. 2018). Water is too significant a source to satisfy the necessities for residential, agricultural and industrial determination (Li et al. 2013a). Especially, a few decades back water defilement exasperated by fluoride and nitrate consumes remained a creating around the world issue and it is the most human wellbeing anxiety. The advancement of fluoride and nitrate is antagonistically impacting water excellence around the world. The water quality of fluoride and nitrate has been completed in a dried and semi-arid region within the entire world (Satyanarayana et al. 2017; Sakram et al. 2018; Laxman et al. 2022).

Various components are impacting the improvement of nitrate concentrations in groundwater, for a case, agrarian runoff, intemperate utilize of fertilizers, destitute development of septic frameworks, spilling metropolitan drains, feedlots, dairy and poultry cultivating, manure frameworks, humanoid and creature wastes (WHO 1998). In this way, high focuses of nitrate have been found in agricultural areas by unreasonable utilization of manure and built-up areas through lots of anthropological and animal wastes (Stadler 2008).

The fluoride concentration in consumption water is fundamental toward stimulating the bones and dental coating, whereas degree of fluoride in water causes fluorosis, which is disturbing a tremendous number of individuals around the world (Satyanarana and Laxman 2017; Sakram et al. 2018). The watershed area of Bachannapeta mandal of Jangaon district, Telangana State, the territory saw fast improvement during past decades regarding urbanization, industrialization and also population growth significantly. The groundwater is imperative for household and industrial determinations. Hence, overexploitation of water happened, and its falling separated quality takes gotten to be a critical challenge within the semi-arid area. Upgrading aquatic assists research about is the way to managing with these issues (Li and Qian 2018) and expending passable data on hydrogeochemistry is important to address the groundwater quality matters.

2. Study area and General Geology

The aerial extent of the research region is 17° 39' to 17° 51' north latitude and 78° 54' to 79° 03' east longitude (Fig. 1). A total of 380 km2 was covered. On the outskirts of the region, the study area consists of rough terrain and monolithic rocks. From 2014 through 2020, the region's average annual rainfall will be 846 mm. The study region's coldest month is January, with a temperature of 14°C, and its warmest month is May, with a temperature of 40°C.

The zone's topography is dominated by a uniform layer of Precambrian granite from the region, which is primarily made up of pink and grey granites. Dolerites, gneisses, and epidote are frequently found in the zone. A substantial portion of a region containing calcium, sodium, and potassium-rich feldspars is covered by granite rock. Granitic rocks, intrusive of dolerites, are visible in the study region's northern and eastern sections (Fig. 2). These dykes play a critical role in regulating the migration of groundwater in the region. Even joints help maintain the level movement of the spring by acting as conduits for the exchange of water (CGWB 2011).

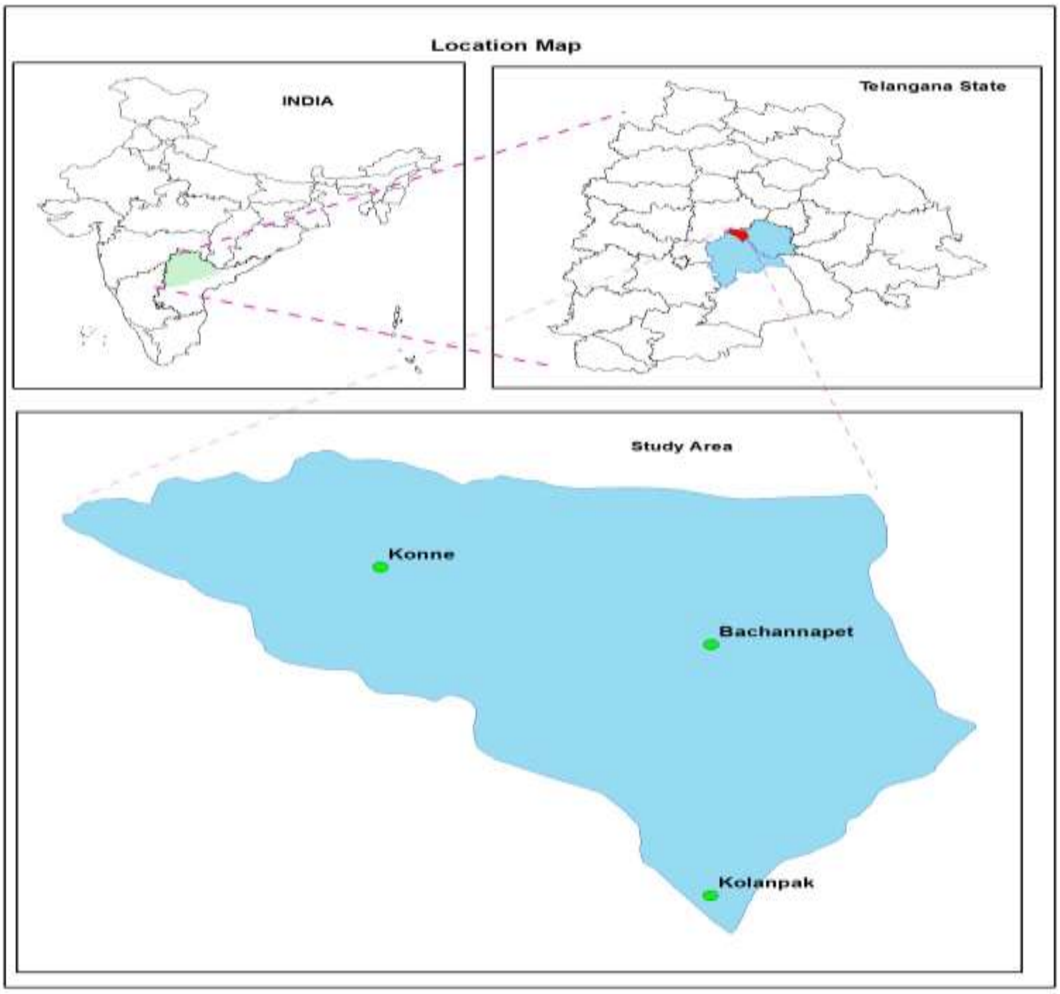

Fig. 1 Location map of the study area

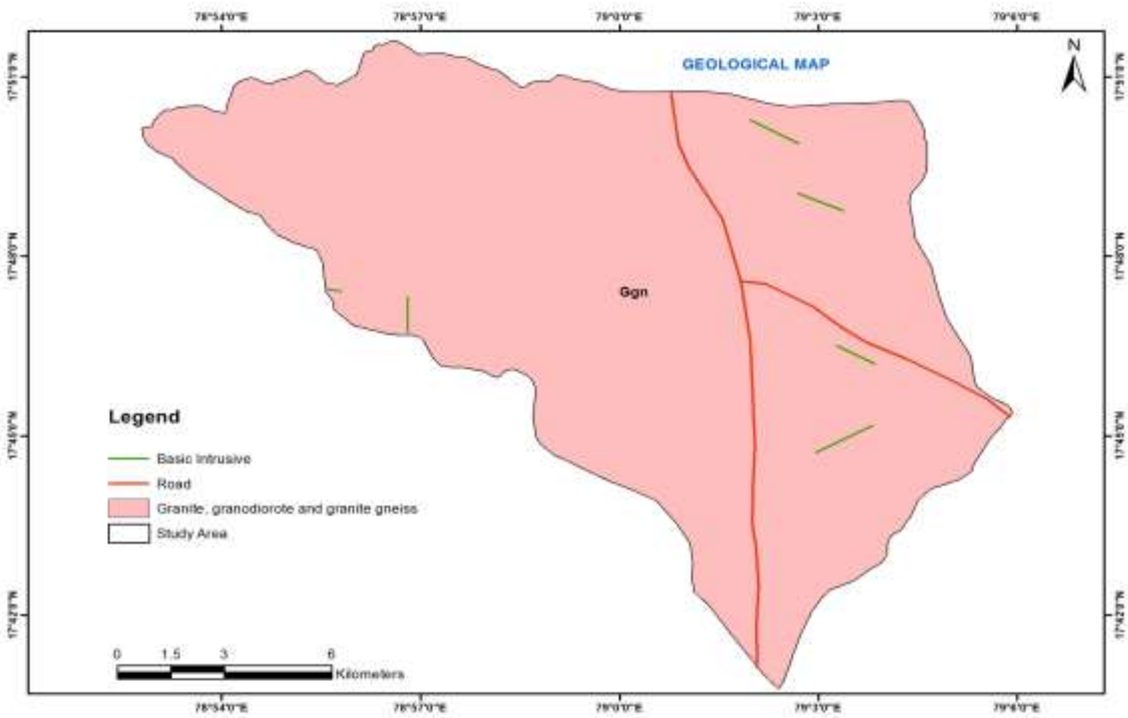

Fig. 2 Geology map of the study area

3. Groundwater sampling

To evaluate the groundwater quality, forty water samples were collected in the watershed area of Bachannapeta mandal, Jangaon district of Telangana State, India. One liter capacity bottle was collected for groundwater samples. 1:1 dilute nitric acid cleaned with bottles and washed with distilled water. Earlier to sample collection, the bottles were washed once more twice with the sample to be collected. After collected water samples directly measured pH/EC/DS meter (Hanna USA H-198130). Expect pH/EC/DS, remaining major ions were analyzed using the standard method (APHA 1995), and detailed statistics of groundwater chemistry of the study region is accessible in Table 1.

Table 1 Statistics of groundwater chemistry of the study area

Variables	Pre-monsoon season					Post-monsoon season				BIS (2012)
	Minimum	Maximum	Mean	% of samples exceeded the limits		Minimum	Maximum	Mean	% of samples exceeded the limits	
pH	7.76	9.26	8.30	18		7.45	8.68	7.99	8	**6.5 - 8.5**
EC (µS/cm)	250	2250	705	-		230	1850	605		**-**
TDS (mg/l)	160	1440	451	28		147	1184	387	18	**500**
TH as CaCO3	95	655	194	5		88	510	174	3	**500**
Ca^{2+} (mg/l)	15	105	31	5		14	82	28	5	**75**
Mg^{2+} (mg/l)	14	96	28	23		13	74	25	20	**30**
Na^{+} (mg/l)	46	402	158	30		38	365	136	18	**-**
K^{+} (mg/l)	1	24	5	8		1	18	4	3	**-**
Cl^{-} (mg/l)	28	877	177	18		22	706	144	18	**250**
CO_3^{-} (mg/l)	0	24	9	-		0	33	4	-	
HCO_3^{-} (mg/l)	24	232	87	-		26	242	88	-	**-**
SO_4^{2-} (mg/l)	23	198	68	-		20	185	77	-	**200**
F^{-} (mg/l)	0.19	4.05	1.56	50		0.12	3.12	1.23	40	**1.5**
NO_3^{-} (mg/l)	28	158	61	53		32	168	68	68	**45**
Gibb's I	0.38	0.98	0.72	-		0.36	0.98	0.69	-	**-**
Gibb's II	0.44	0.92	0.76	-		0.43	0.92	0.74	-	**-**

Table 2 Groundwater classifications on the basis of TDS (Freeze and Cherry 1979); Davis and Dewiest and TH (Sawyer and McCarthy 1967)

Parameters	Range	Water type/Classification	% of groundwater samples pre-monsoon	% of groundwater samples post-monsoon
TDS (mg/L)	<1000	Fresh	95	97
	1000-10000	Brackish	5	3
	10000-100000	Saline	-	-
	>100000	Brine	-	-
TH (mg/L)	<75	Soft	-	-
	75-150	Moderately hard	30	50
	150-300	Hard	63	44
	>300	Very hard	7	6

4. Human Health Risk Assessment (HHRA)

The HHRA is an approach to character and opportunity of unwell-health consequences in humans who used infected water frequently (Li et al. 2013a, 2019b), on these observations, consuming aquatic intake turned into important publicity pathway for nitrate (NO_3^-) and fluoride (F^-). The IRIS (incorporated chance facts gadget model brought via US Environmental safety business enterprise, USEPA 2004) stands to degree the publicity amount (E) via absorption pathway and possibly non-carcinogenic hazard of threat quotient or hazard index (HQ) (He and Wu 2019).

$$ADD = \frac{CGW \times IR \times ED \times EF}{ABW \times AET}$$

$$HQ = \frac{ADD}{RfD}$$

where ADD is defined as a dosage of daily NO_3^- and F^- (mg/kg/day), CGW is the absorption in water (mg/L), rate of humanoid absorption is 2.5 L/day for adults, and 0.78 L/day for children marked with IR, the contact period for adults is 70 and for children is 6 denote with ED, EF is defined as contact frequency in days or years, the mean body weight (ABW) has been taken as 65 kg for adults and 15 kg for children. AET is defined as the average time (days: 25550 and 2190 for adults and children), the non-carcinogenic for hazard quotient is denoted as HQ and the reference dose of fluoride and nitrate 4.00 mg/kg-day and 1.1 mg/kg-day, respectively is marked with RfD (included hazard statistics System, USEPA 2004).

The human risk catalog translates a 10^{-6} hazard degree for chemicals, and HQ is 1 for non-carcinogenic, if someone is uncovered each day for an entire life to 1 µg/L of the nitrate/fluoride consistent with a liter of consuming water, the unit risk = 2 x 10^{-6} per µg/L, meaning extra cancer instances remain predicted to increase per a million persons.

5. RESULTS AND DISCUSSION

5.1 General groundwater characteristics

The pH value of the groundwater in the region is indicating alkaline in nature with a mean of 8.30 and 7.45 in pre and post-monsoon seasons. The mean values of EC and TDS for pre-monsoon was 705 µS/cm and 451 mg/L, whereas post-monsoon seasons, it was 605 µS/cm and 387 mg/L respectively. The mean concentrations of Ca^{+2}, Mg^{+2}, Na^{+}, K^{+}, Cl^{-}, CO_3^{-}, HCO_3^{-}, and SO_4^{-2} vary from 31 mg/L, 28 mg/L, 158 mg/L, 5 mg/L, 177 mg/L, 9 mg/L, 87 mg/L and 68 mg/L in pre-monsoon season, whereas post-monsoon season the concentrations vary from 28 mg/L, 25 mg/L, 136 mg/L, 4 mg/L, 144 mg/L, 4 mg/L, 88 mg/L and 77 mg/L respectively (Table 1). The study region dominance for cations was Na>Ca>Mg>K for anions it was Cl>HCO_3SO_4>NO_3>CO_3>F for groundwater in pre and post-monsoon seasons.

The TDS values vary from 160 - 1440 mg/L and 147 – 1184 mg/L in both monsoon periods. About 28% and 18% of the groundwater samples are exceeding the permissible limits of TDS 500 mg/L (BIS 2012) prescribed limits of drinking purposes in both monsoon periods. According to (Davis and De Wiest 1966, Freeze and Cherry 1979) classification, groundwater samples are classified with the TDS values. As per the classification of the study region, around 95% is fresh and 5% are brackish water quality categories in pre monsoon season and Post-monsoon season, 97% fresh and 3% brackish water categories respectively (Table 2).

The TH as $CaCO_3$ values ranges from 95 - 655 mg/L and 88 - 510 mg/L. Around 5% and 3% of the water samples are exceeded the permissible limit of 500 mg/L (BIS 2012) prescribed drinking water purposes. According to Sawyer and McCarty (1967) classification groundwater samples are which indicates 30% moderately hard, 63% hard and 7% very hard categories in pre-monsoon and post-monsoon seasons about 50%, 45% and 5% which indicates moderately hard, hard and very hard categories respectively (Table 2).

5.2 Spatial distribution of Nitrate

The groundwater trend was cumulative last few past decades in nitrate pollutants, because of the fast development of urban growth expansion, industrial development, and large utility of nitrate using agriculture fertilizers and horticulture activities. The excessive nitrate spatial interpolation in consumption water can position a threat to human health (Zhang et al. 2018). The NO_3^- values vary from 28 to 158 mg/L with a mean of 61 mg/L and 32 - 168 mg/L, with a mean of 68 mg/L in both monsoon seasons (Table 1, Fig. 3a and 3b). The Spatial interpolation of the nitrate 61% and 68% of water samples exceed the 45 mg/L limit for drinking water specifications in both monsoon seasons (WHO 2011) (Fig. 4).

Oenema et al. (2005) have determined that nitrate by and large percolates into the aquifer regime from the extensive farming, horticulture, households, and manufacturing wastes. The diammonium phosphate, urea, and super-phosphate fertilizers are regularly used, which can leach into the sub-surface. Nitrate also can be drain away from the soils, for those reasons enhance the nitrate content in groundwater because of the extensive utility of nitrate fertilizers (Sakram et al. 2018). Thus, nitrate gathered in water through various ways that incorporate shallow groundwater, domestic sewage, manures, agriculture and horticulture wastes (Oenema et al. 2005; Lokesh et al. 2013).

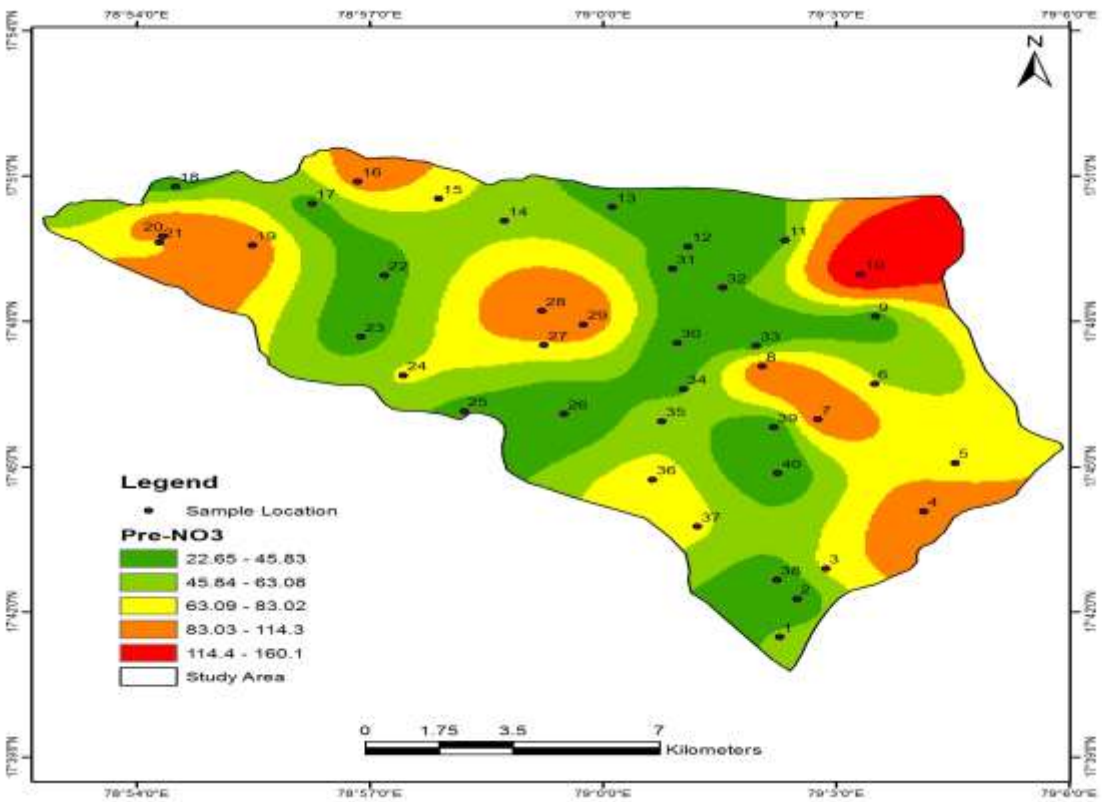

Fig. 3a Spatial distribution of NO_3^- concentration map in the pre-monsoon season

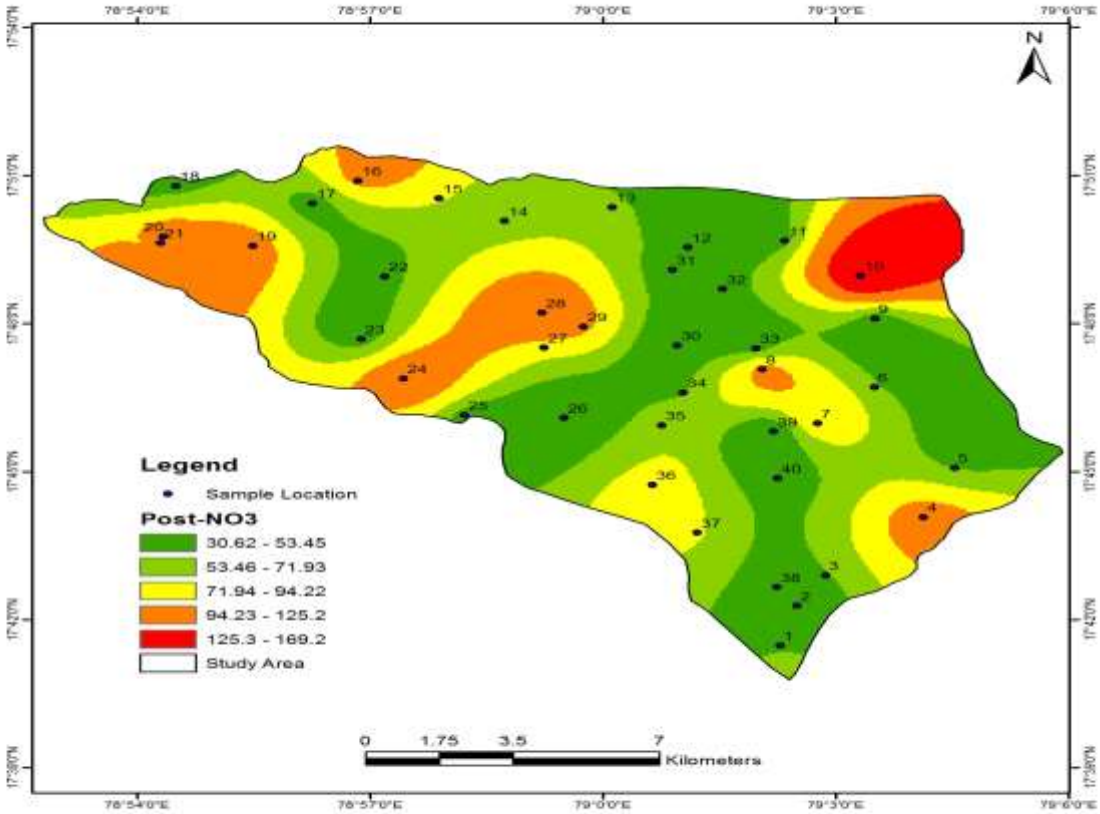

Fig. 3b Spatial distribution of NO_3^- concentration map in the post-monsoon

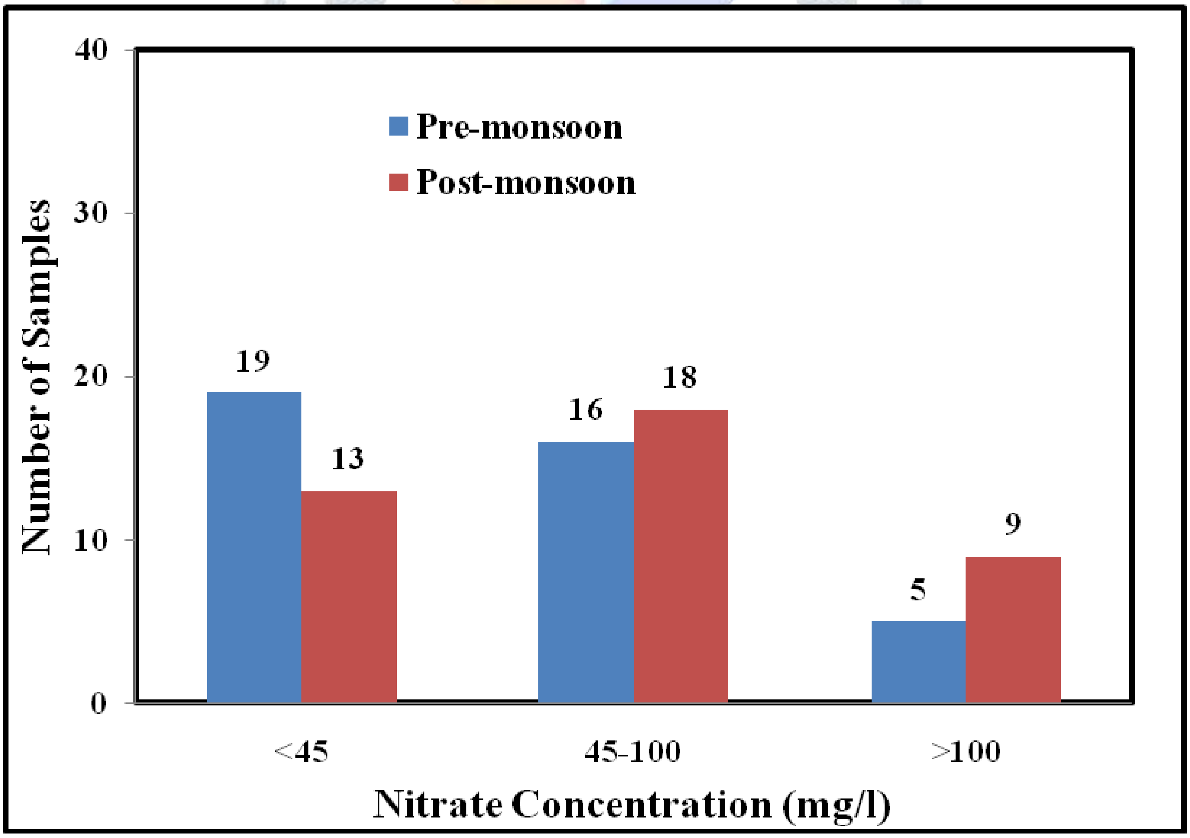

Fig. 4 Nitrate concentration for risk evaluation for drinking water in pre and post-monsoon seasons

5.3 Spatial distribution of Fluoride

The fluoride concentration of the drinking water limits is 1.5 mg/L (WHO 2011; BIS 2012) used as overwhelming water effects in dental and skeletal fluorosis (Laxman Kumar et al. 2019), within the observe region the fluoride spatial interpolation levels varies from 0.19 to 4.05 mg/L, by a mean of 1.56 mg/L and 0.12 to 3.12, with a mean of 1.23 mg/L in both monsoons. Around 50% and 40% of samples are have been exceeded the desirable limit is 1.5 mg/L (BIS 2012) standards (Table 1). The high spatial interpolation of fluoride turned into delineated with a different pattern, shown in Fig. 5a and 5b. The high fluoride distribution is identified in northern, eastern, north-eastern and north-western parts of the region (Fig. 6), the alkaline nature of water increases the anionic exchange in controlling the fluoride content in the aquifer regime (Saxena and Ahmed 2003).

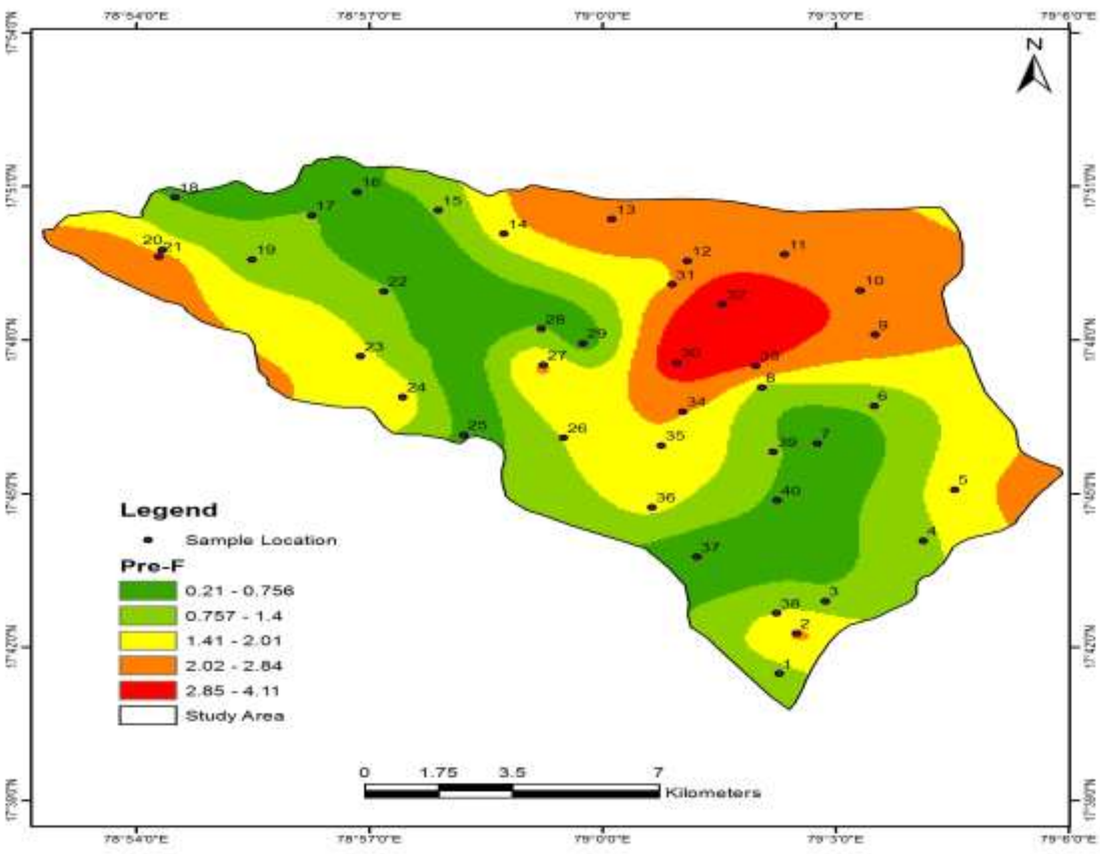

Fig. 5a Spatial distribution of fluoride concentration map in the pre-monsoon

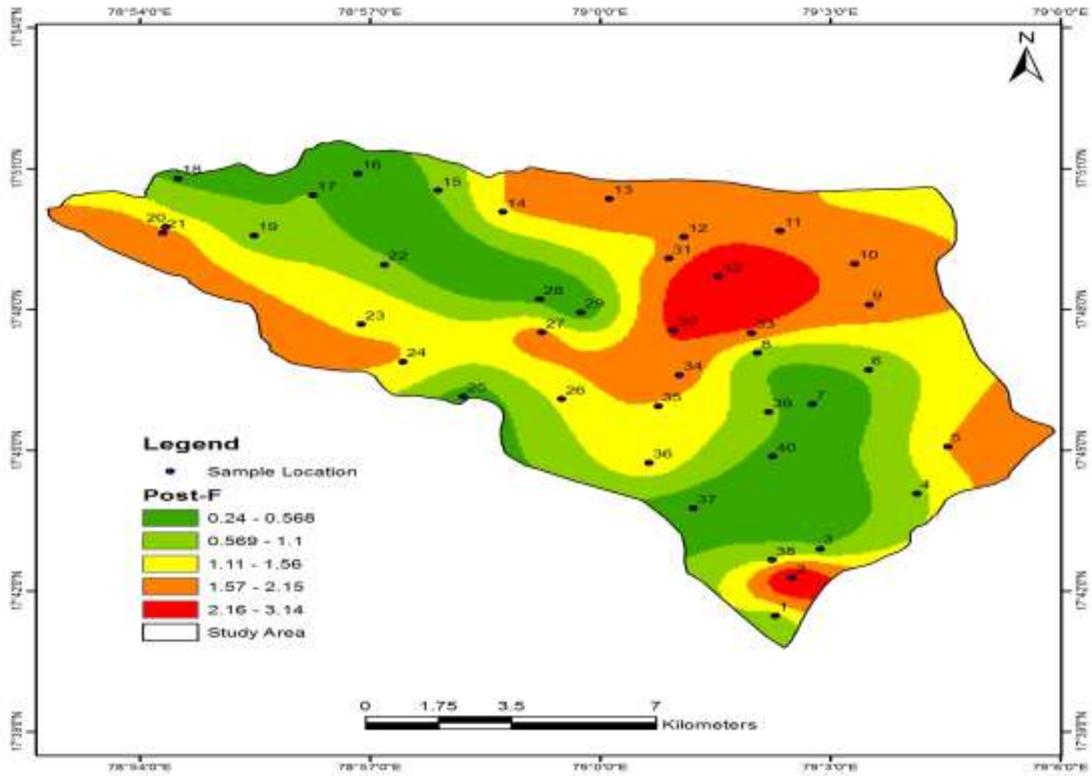

Fig. 5b Spatial distribution of fluoride concentration map in the post-monsoon

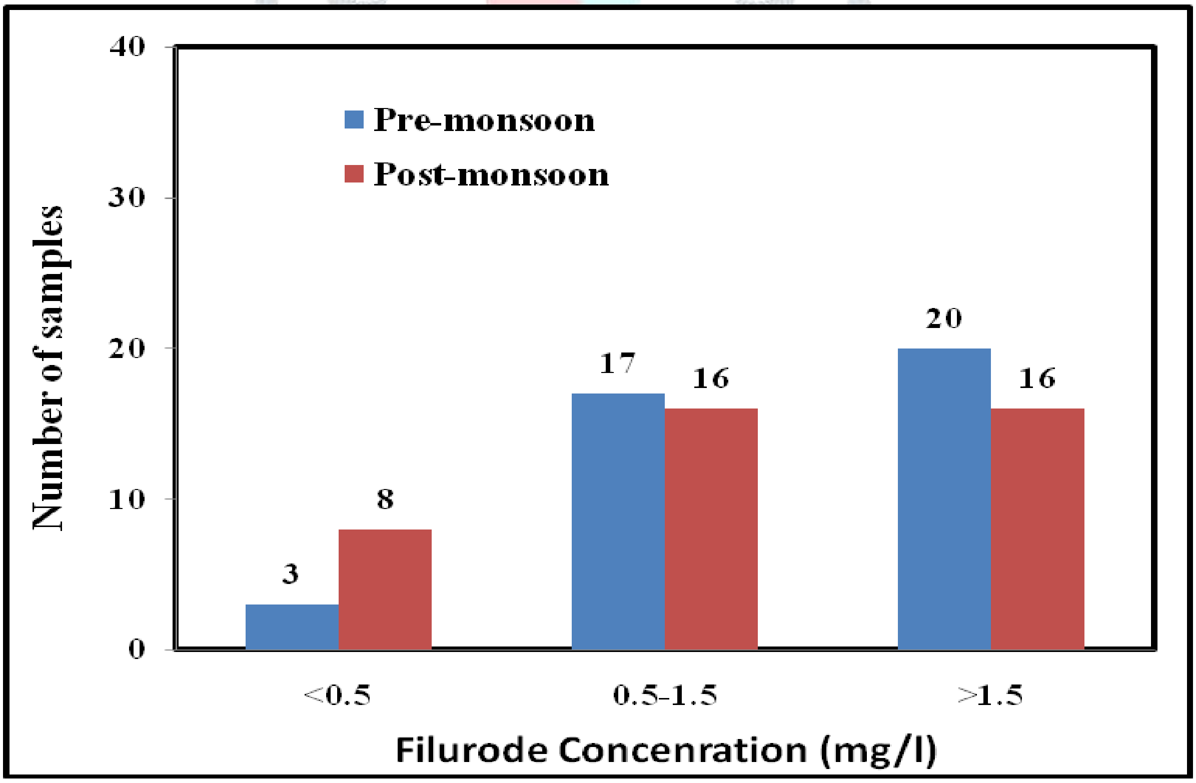

Fig. 6 Fluoride concentration for risk evaluation for drinking water in pre and post-monsoon season

5.4 Hydrochemical facies

The Piper chart comprises cation, anion triangular areas and a central diamond-shaped field (Piper 1944). Three areas safe the joining of major practices as it were, which are cations like alkaline earth, alkalis, weak acid, and strong acid (Karanth 1987). The Piper Trilinear classification of the study region which is classified into six categories during pre and post-monsoon seasons which are around Na-Cl of (62% and 62%), Mixed CaMgCl of (28% and 30%) and CaCl of (10% and 8%) predominance of water types (Fig. 7).

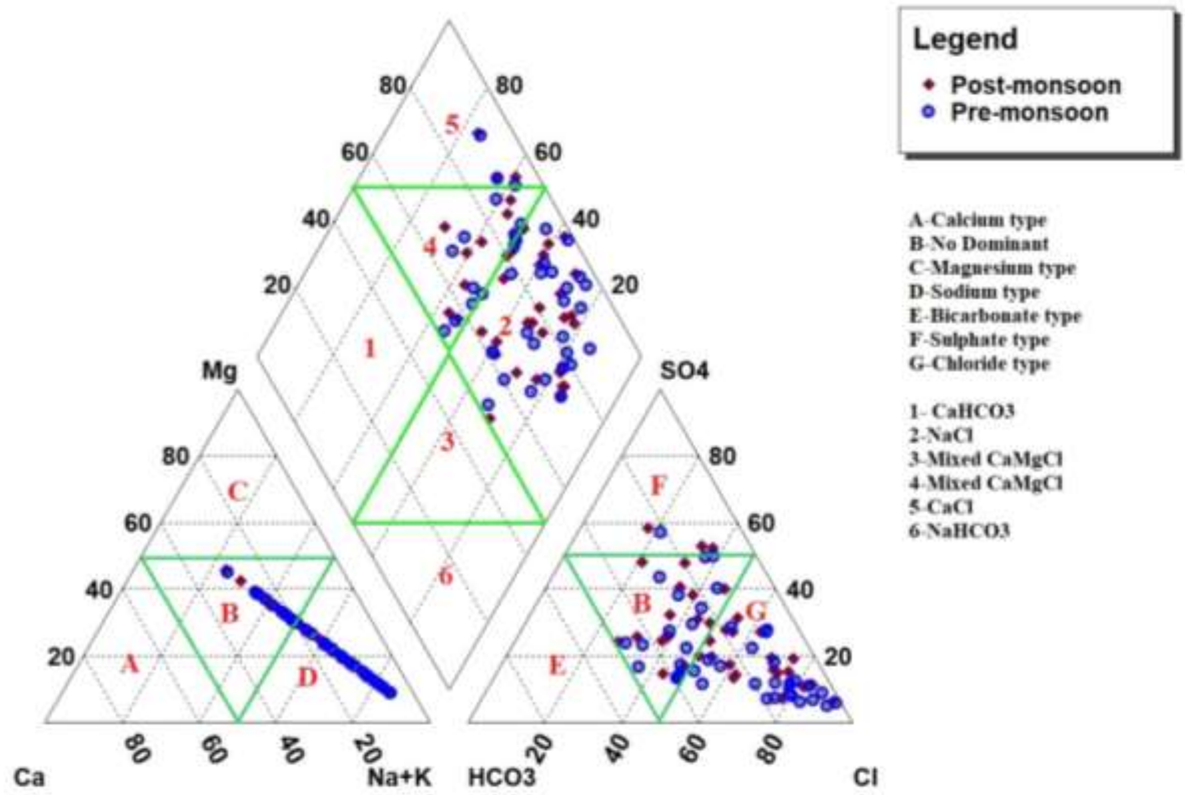

Fig. 7 Piper trilinear classification of groundwater in pre and post-monsoon seasons

5.5 Gibb's diagram

The component of water-rock collaboration monitoring the groundwater chemistry can be concentrated by plotting TDS vs. $Na^+/(Na^++Cl^-)$ and TDS vs. $Cl^-/(Cl^-+HCO_3^-)$ using Gibb's diagram (Gibbs 1970). As per Gibbs diagram majorly three categories, that is, precipitation dominance, rock dominance, and evaporation dominance. Gibb's estimation is meq/L.

Gibb's ratio I (for anion) = $Cl^- / (Cl^- + HCO_3^-)$

Gibb's ratio II (for cation) = $(Na^+ + K^+) / (Na^+ + K^+ + Ca^{+2})$

Gibbs proportion I of the consider region esteems extend of pre, post-monsoons and average from 0.38 – 0.98, 0.72 meq/L and 0.36 – 0.98, and 0.69 meq/L (Table 1). Gibbs proportion II for the study region regards extend from pre, post-monsoons and an average 0.44 – 0.92, 0.76 meq/L and 0.43 – 0.92, 0.74 meq/L (Table 1). The Gibbs chart illustrated that the examination region mostly rock dominance field (Fig. 8). The present investigation uncovers that the groundwater chemistry is significantly affected by rock dominance, which shows that the foremost mechanism of weathering of rock-forming minerals because of the whole territory of involved by granitic gneisses (Satyanarayana et al. 2017).

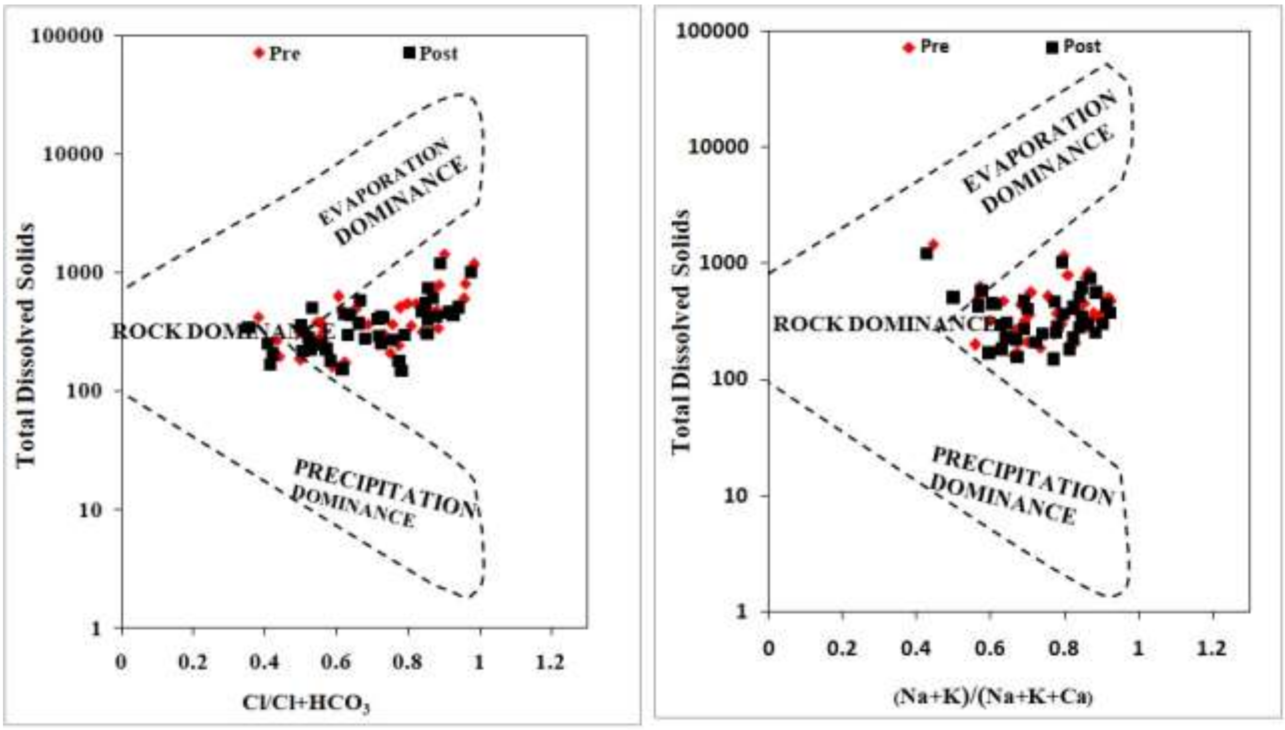

Fig. 8 Gibb's plot from the study area is rock-dominant factor controlling the groundwater chemistry in pre and post-monsoon seasons

5.6 Health risk assessment of the study area

The hazard quotient and total health index of study region of non-carcinogenic for adults and children are evaluated for both monsoon periods. HQ-fluoride, HQ-nitrite for adults ranges from 0.12 – 2.60 and 0.67 – 3.80, with a mean of 1.00 and 1.80, for children HQ-fluoride and HQ-nitrite through drinking water intake ranges from 0.16 – 3.51 and 0.91 – 5.14 in pre-monsoon season (Table 3a) and post monsoons of HQ Fluoride and Nitrate adult values ranges between 0.08 – 2.00 and 0.77 – 4.04, with a mean 0.80, 1.67 and HQ fluoride and nitrate in children values ranges between 0.10 – 2.70 and 1.04 – 5.46, with a mean of 1.08, 2.26 (Table 3b). As per the recommended standard of the United States, the Environmental Protection Agency is HQ as 1 for each variable in terms of human health (USEPA 2014).

Hazard quotient of the study region around 40% and 53% of the groundwater samples for HQ-fluoride and HQ-nitrite for children and 18% and 45% of samples for adults HQ-fluoride and HQ-nitrite have been exceeded the desirable limits in pre-monsoon season (Fig. 9). The post-monsoon season around 28% and 60% HQ-fluoride and HQ-nitrite for children; HQ-fluoride and HQ-nitrite 5% and 40% for adults in the study region. Total hazard index of the study region for HQ-fluoride and HQ-nitrite ranges from 1.19 – 5.39 and 1.05 – 4.46, with a mean of 2.48 and 2.44 for adults and children values ranges from 1.60 – 7.28 and 1.43 – 6.02, with a mean of 3.35 and 3.30 respectively in pre and post-seasons. However, it may contain a health risk of non-carcinogenic for children than adults for fluoride and nitrate contamination in groundwater from the studied region.

Table 3a Hazard Quotient (HQ) and Total Hazard Index (THI) for Adults and Children in the study area of pre-monsoon season

Sample No.	HQ of Fluoride in Adult	HQ of Nitrate in Adult	THI	HQ of Fluoride in Children	HQ of Nitrate in Children	THI
1	0.77	1.15	**1.92**	1.04	1.56	**2.60**
2	1.33	0.84	**2.17**	1.79	1.14	**2.93**
3	0.62	1.59	**2.21**	0.84	2.15	**2.98**
4	0.79	2.45	**3.24**	1.07	3.32	**4.38**
5	1.13	1.73	**2.87**	1.53	2.34	**3.87**
6	0.62	1.56	**2.18**	0.84	2.11	**2.95**
7	0.12	2.45	**2.57**	0.16	3.32	**3.48**
8	0.80	2.36	**3.16**	1.08	3.19	**4.27**
9	1.58	0.91	**2.50**	2.14	1.24	**3.38**
10	1.59	3.80	**5.39**	2.15	5.14	**7.28**
11	1.45	1.01	**2.46**	1.96	1.37	**3.32**
12	1.41	0.91	**2.32**	1.91	1.24	**3.14**
13	1.70	1.01	**2.71**	2.30	1.37	**3.66**
14	1.09	1.35	**2.44**	1.47	1.82	**3.29**
15	0.56	1.63	**2.19**	0.76	2.21	**2.97**
16	0.38	2.21	**2.59**	0.51	2.99	**3.50**
17	0.51	0.96	**1.47**	0.69	1.30	**1.99**
18	0.46	0.91	**1.37**	0.62	1.24	**1.85**
19	0.69	2.36	**3.04**	0.93	3.19	**4.11**
20	1.07	2.69	**3.76**	1.45	3.64	**5.09**
21	1.52	1.83	**3.35**	2.05	2.47	**4.52**
22	0.57	0.96	**1.54**	0.78	1.30	**2.08**
23	1.01	0.91	**1.93**	1.37	1.24	**2.60**
24	1.12	1.56	**2.68**	1.51	2.11	**3.62**
25	0.40	0.91	**1.32**	0.55	1.24	**1.78**
26	0.91	0.67	**1.58**	1.23	0.91	**2.14**
27	1.33	1.88	**3.21**	1.80	2.54	**4.34**
28	0.52	2.69	**3.21**	0.71	3.64	**4.35**
29	0.29	2.36	**2.64**	0.39	3.19	**3.58**

30	2.21	0.67	**2.88**	2.99	0.91	**3.90**
31	1.31	0.77	**2.08**	1.78	1.04	**2.82**
32	2.60	1.01	**3.61**	3.51	1.37	**4.88**
33	1.82	0.91	**2.73**	2.46	1.24	**3.70**
34	1.31	1.06	**2.37**	1.78	1.43	**3.21**
35	1.25	1.35	**2.60**	1.69	1.82	**3.51**
36	0.98	1.73	**2.71**	1.33	2.34	**3.67**
37	0.19	1.63	**1.83**	0.26	2.21	**2.47**
38	0.91	0.87	**1.78**	1.23	1.17	**2.40**
39	0.58	0.67	**1.25**	0.78	0.91	**1.69**
40	0.42	0.77	**1.19**	0.56	1.04	**1.60**

Table 3b Hazard Quotient (HQ) and Total Hazard Index (THI) for Adults and Children in the study area of post-monsoon season

Sample No.	HQ of Fluoride in Adult	HQ of Nitrate in Adult	THI	HQ of Fluoride in Children	HQ of Nitrate in Children	THI
1	0.08	1.25	1.33	0.10	1.69	1.79
2	0.14	0.91	1.05	0.19	1.24	1.43
3	0.14	1.25	1.39	0.19	1.69	1.88
4	0.21	2.60	2.81	0.29	3.51	3.80
5	0.21	1.25	1.46	0.29	1.69	1.98
6	0.22	1.35	1.57	0.30	1.82	2.12
7	0.29	2.21	2.51	0.40	2.99	3.39
8	0.29	2.45	2.75	0.40	3.32	3.71
9	0.35	0.99	1.34	0.48	1.33	1.81
10	0.42	4.04	4.46	0.56	5.46	6.02
11	0.42	1.11	1.53	0.57	1.50	2.07
12	0.48	1.06	1.54	0.65	1.43	2.08
13	0.49	1.39	1.88	0.66	1.89	2.54
14	0.49	1.49	1.98	0.66	2.02	2.67
15	0.56	1.78	2.34	0.75	2.41	3.16
16	0.57	2.43	3.00	0.77	3.28	4.05
17	0.61	1.11	1.71	0.82	1.50	2.32
18	0.63	1.06	1.69	0.85	1.43	2.28
19	0.66	2.72	3.38	0.89	3.67	4.57
20	0.78	2.98	3.76	1.06	4.03	5.09
21	0.88	2.21	3.10	1.20	2.99	4.19
22	0.90	1.15	2.06	1.22	1.56	2.78
23	0.94	1.06	1.99	1.27	1.43	2.70
24	0.94	2.91	3.84	1.27	3.93	5.20
25	0.97	1.06	2.03	1.32	1.43	2.75
26	0.99	0.77	1.76	1.33	1.04	2.37
27	1.00	2.04	3.04	1.35	2.76	4.11
28	1.10	2.88	3.99	1.49	3.90	5.39
29	1.10	2.45	3.55	1.49	3.32	4.81
30	1.12	0.77	1.88	1.51	1.04	2.55
31	1.13	0.96	2.09	1.53	1.30	2.83
32	1.17	1.11	2.27	1.58	1.50	3.07
33	1.18	1.06	2.24	1.59	1.43	3.02
34	1.19	1.25	2.44	1.60	1.69	3.29
35	1.19	1.56	2.75	1.61	2.11	3.72

36	1.25	1.92	3.17	1.69	2.60	4.29
37	1.29	1.80	3.10	1.75	2.44	4.19
38	1.44	1.06	2.49	1.94	1.43	3.37
39	1.79	0.77	2.56	2.43	1.04	3.47
40	2.00	1.06	3.06	2.70	1.43	4.13

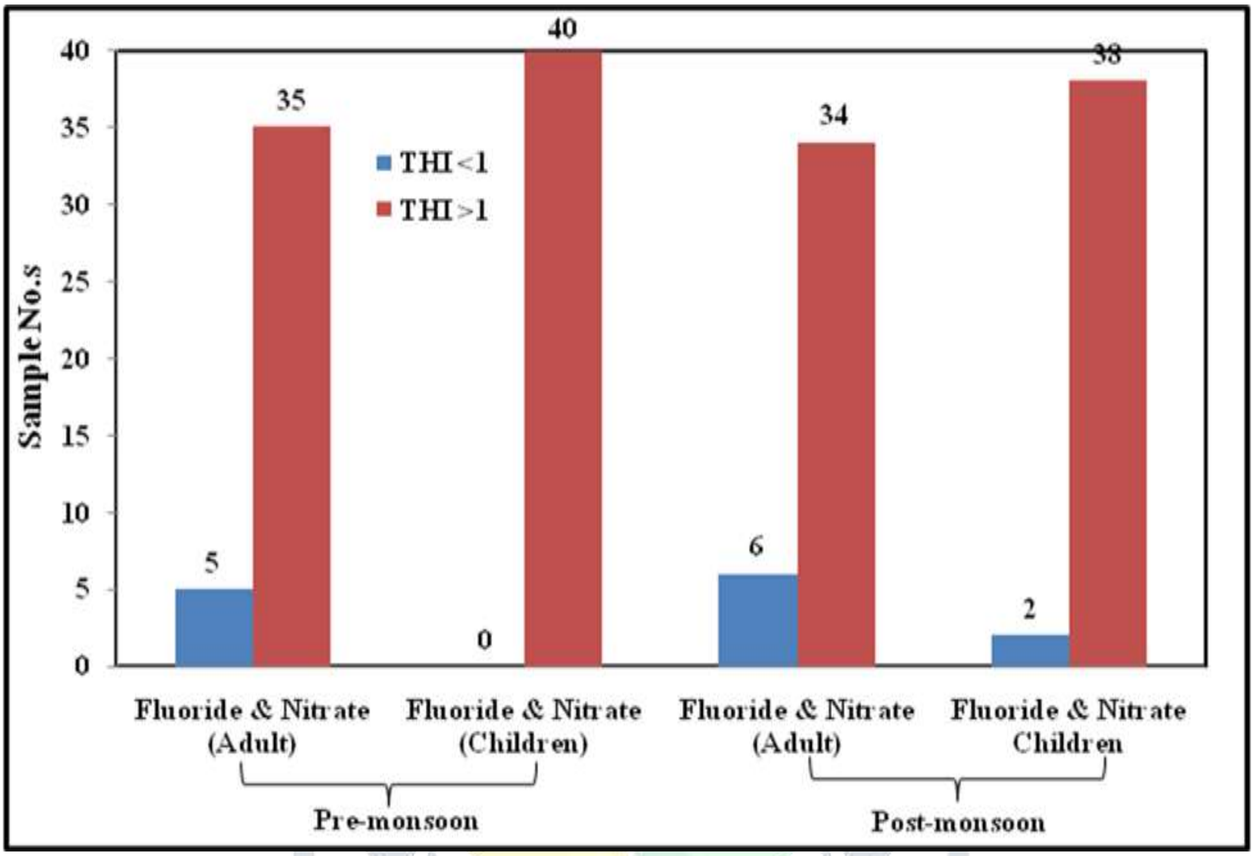

Fig. 9 Total Hazard Index for adults and children in pre and post-monsoon seasons

6. Conclusion

The pH is slightly alkaline. The study region's high fluoride concentrations can be found in the north, east, north-east, and south-west, owing to the preponderance of F-rich rocks in the granitic terrain. The high nitrate concentration implies that fertilisers and residential sewage could be leached into the groundwater. During both seasons, the piper diagram classified categories NaCl and Mixed CaMgCl are the result of weathering and rock dissolution, according to the piper diagram. The Gibbs diagram depicts a primarily rock-based dominance. Groundwater quality variation is mostly described by mineral dissolution from rock water interactions in the aquifer, which is the outcome of the evolution of anthropogenic activities and ion exchange processes within the groundwater, according to factor analysis. The extracted all four-factor components rotated cumulative variance from the research region, which was dominated by hydrogeochemical characteristics including silicate weathering minerals, cation, and anthropogenic variables that influenced groundwater contamination. The hazard quotients for nitrate and fluoride groundwater samples surpassed the USEPA's tolerance limit for the non-carcinogenic danger of 1.0 in children and adults, indicating that children in the research region face a greater health risk than adults.

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