Health risk assessment of nitrate and fluoride toxicity in groundwater contamination in the semi-arid area of Medchal, South India

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Abstract
Hydrogeochemical controlling variables for the high rate of groundwater contamination in a shallow hard rock aquifer of the semi-arid region of Medchal District, Telangana State, South India, and its associated health risk to children and adults were studied in detail. A total of 56 groundwater samples were analysed for major ion chemistry in pre- and post-monsoon seasons in 2019 year. Spatial distribution, hydrochemical facies, water–rock interaction, health risk assessment, carcinogenic risk, and principal component analyses were carried out to assess the water quality. Spatial distribution of nitrate and fluoride concentrations, high values were observed in the northern, southern, central, and south-western parts of the region. In terms of \( \text{NO}_3^- \), about 88% and 63% and for \( \text{F}^- \) 45% and 32% of the groundwater samples are non-acceptable limits of nitrate 45 mg/l and fluoride 1.5 mg/l during pre- and post-monsoon seasons, respectively. Modified Gibb’s plot showed the majority of the area is dominated by rock dominance and evaporation mechanisms. Statistical analysis reveals that water chemistry is governed by weathering of feldspar minerals and the cation exchange reaction mechanism. The petro-graphical studies revealed the dominance of plagioclase, orthoclase, quartz, biotite, apatite, and hornblende minerals in the host rock. The factor analysis results reveal that the geogenic and anthropogenic activities contribute to groundwater chemistry. Health risk assessment was carried out by calculating the hazard quotient (HQ) on the basis of intake exposure of groundwater, as per the USEPA. Results were obtained for total hazard index value greater than 1 for adults and children, which causes non-cancerous health effects.

Keywords Health risk assessment · Fluoride and nitrate · Spatial distribution · Gibb’s plot · Hazard quotient · Medchal · South India

Introduction
Human beings rely heavily on natural resources. Fresh air and clean water, in particular, are essential for people to survive on this globe. Groundwater and surface water are the two most significant sources of water for residential, agriculture, and industrial applications (Laxman et al. 2019; Muralidhara and Sunitha 2020). Due to a lack of surface water, one-third of the world's population, particularly in arid and semi-arid countries, relies on groundwater for their daily requirements, particularly for drinking (USEPA 2014). As a result of natural environmental changes and human activities such as agricultural and industrial activities, groundwater quality is gradually deteriorating, resulting in a water shortage crisis and a host of environmental challenges (Satyanarayana et al. 2017; Toolabi et al. 2021). The groundwater contaminations aggravated by nitrate and fluoride concentrations affect human health risk for the past two decades. Nitrate and fluoride levels are being harmed by poor groundwater quality around the world. Several researchers on water quality in terms of fluoride and nitrate have been undertaken in arid and semi-arid regions around the world in recent years (Satyanarayana et al. 2017; Kadam et al. 2020).

Agricultural runoff, excessive fertilizer use, inadequate septic system construction, spilling city drains, slaughterhouses, dairy and poultry farming, manure systems, humanitarian and animal wastes, and so on all have an impact on the elevated nitrate concentrations in groundwater (USEPA...
High focuses of nitrate have been found in agricultural areas by excessive utilization of manure and built-up areas through lots of anthropological and animal wastes (He and Wu 2019; Wagh et al. 2019). The fluoride contains in drinking water are main causes for the enamel of dental fluorosis and wrinkle in bones effect of people worldwide. In India, 28 territories and around 66 million people are suffering from fluorosis (Satyanarana et al. 2017).

Fluorine is the common elements found in soil and water and introduced by USEPA as one of the hazardous chemical contaminants (Amiri and Berndtsson 2020; Toolabi et al. 2021; Sohrabi et al. 2021). Fluoride naturally found in granite, gneisses, basalt and shale rocks, and fluoride ions enters water environments significantly via different pathways viz., beryllium extraction, bricks and iron works, aluminium smelters, coal-based power stations, and industries of electroplating. Fluoride in potable water in certain concentrations causes adverse effects including tooth decay (< 0.50 mg/L), fluorosis (1.50–5 mg/L), and skeletal fluorosis (5–40 mg/L) (Kimambo et al. 2019; Vithanage and Bhattacharya 2015). The high concentration (> 10 mg/L) of F− is commonly associated with arthritis, neurological disorders, thyroid, cancer, infertility, and hypertension. Fluoride also affects the teeth and skeleton and leads to change in the DNA structure (Kimambo et al. 2019). Similarly, Nitrate (NO3−) concentrations are widely found in nitrogen-containing fertilizers. Improper disposal of wastes animal feedlots, dairies, agricultural land, and landfills leachate can elevate the nitrate content of water bodies (Toolabi et al. 2021). The presence of NO3− in potable water is harmful to animal and human health. The drinking water guidelines are designed to prevent adverse health outcomes such as methemoglobinemia in newborns. Pregnant women, infants, and children are more vulnerable to high concentrations of NO3− (Eggers et al. 2018). The increase in NO3− in water bodies creates problems such as deteriorating water quality, creating eutrophication, and producing toxic algal blooms (Briki et al. 2017). Moreover, the presence of excessive-high concentrations of NO3− in drinking water may create various diseases, including spontaneous abortions, thyroid disorders, cancer, teratogenesis, mutagenesis, and methemoglobinemia (blue baby syndrome) (Jinling et al. 2018). Assessing the risks of drinking polluted groundwater to human health is important for controlling water pollution and ensuring safe drinking water sources. Several researchers have done a variety of investigations from the viewpoint of concepts, processes, etc., thereby providing a framework for calculating the risk of polluted water (Zafarzadeh et al. 2020) and investigated the impact of fluoride-containing minerals found in hornblende–biotite gneiss and granites, as well as seeping and uncontrolled fertilizer and pesticide use in the Shanmuganadhi river basin in Tamil Nadu, India, on human health risks from nitrate and fluoride ions pollutants (Karunanidhi et al. 2019). According to studies, children are more vulnerable to non-carcinogenic risk than adults. Reduction in groundwater quality is owing to wet weather by observing the interaction of groundwater with granites and gneissic granites with pegmatite veins in a dry climate, as well as the effects of poor drainage conditions (Subba Rao et al. 2020a, b).

During recent time, an increasing alarm regarding the quality of groundwater and its impact on human health due to intake of high nitrate and fluoride drinking water, various policies, guidelines, and human health risk assessment (HRA) model were estimated and its significance on human health via intake through various pathways was adopted (USEPA 2014). Various researchers all over the world adopted these policies and guidelines to delineate the adverse effects of nitrate and fluoride and other contamination on human health (Ayoob and Gupta 2006; Subba Rao et al. 2020b; Karunanidhi et al. 2020).

Medchal-Malkajgiri is one of the newly formed 33 districts of Telangana State, South India, and the region is growing with rapid urbanization, industrialization and also population increases significantly. The study region is granitic terrain dominant semi-arid. Over-exploitation of groundwater has occurred, and its decreasing water quality has become a major concern in the studied area. The region’s goals are to define the spatiotemporal distribution and incidence of nitrate and fluoride contaminations, as well as the hydrogeochemical mechanisms that affect nitrate and fluoride enrichment. The total hazard index was used to quantify the health risks to the population who are drinking highly polluted groundwater. The findings of this study aid in the recognition of the severity of various sensitive zones at a specific site, allowing for the implementation of effective solutions to improve groundwater quality and human health.

### The study region and general Geology

Medchal region aerial extent of latitude 17° 37’ to 18° 02’ north and longitude 78° 38’ to 79° 77’ east (Fig. 1). The total area covered of 1084 km². The study area consists of rocky terrain and monolithic rocks on the outskirts of the region. The land use/land covered in the study region like agricultural plantation, barren rocky, core-urban, crop land, forest, forest plantation, hamlets, mining/industrial, settlements, reservoir/tanks, river/stream/drain, scrub land-open, road network and villages is shown in Fig. 2. The regular yearly rainfall of the region is 866 mm during the year 2013–2018 (Table 1 and Fig. 3). Seasonally, rainfall is distributed as follows: 57% in the south-west monsoon, 10% in the north-east monsoon, 0.4% in winter, and 33% in summer.

The topography of the region is homogenous comprising of Precambrian granite which is mainly comprised of pink
and grey granites. Amphibolites, quartz veins, basic dyke, and migmatites frequently traverse the region. The granite rock covers a significant part of a region with calcium, sodium, and potassium-rich feldspars. The accessory minerals are contained fluorite of granitic terrain such as and apatite \([\text{Ca}_5 (\text{PO}_4)_3 (\text{F, Cl, OH})]\), hornblende \([\text{Ca}_5 (\text{Mg, Fe, Al})_3 (\text{Al, Si})_8 \text{O}_{22} (\text{OH})_2]\) and biotite \([\text{K(Mg, Fe)}_3 (\text{AlSi}_3\text{O}_{10}) (\text{F, OH})_2]\), these minerals have noted the sources of fluoride into the groundwater chemistry. In the study region granitic rocks, intrusive dolerites are visible in the southern and south-eastern parts. These dykes form important structural features controlling the movement of groundwater within the region. Joints are most commonly observed. Vertical joints are conduits for the transfer of water while horizontal joints help to maintain the level continuity of the aquifer (CGWB 2013). Amphibolites occur in eastern part, quartz veins are south-western and south-eastern parts, migmatites are eastern and south-eastern parts of the region. The geological map of the study region is shown in Fig. 4.

**Materials and methodology**

**Sampling and laboratory analysis**

To evaluate the groundwater quality, 56 water samples were collected in and around of Medchal District of Telangana State, India, during a period of pre-monsoon (May 2019) and post-monsoon (December 2019). One-litre capacity bottle was used to collect groundwater samples, 1:1 dilute nitric acid was used to clean the bottles and washed with distilled water. In the field before collecting the samples in once again washed with the same sample, following the standard procedure (APHA 2012). After collected, water samples were directly measured for pH/EC by hand-held meters (Hanna USA H-198130). The TDS values are calculated by multiplying 0.64 with EC values.

The major ions like cations (calcium, magnesium, sodium, and potassium); anions (bicarbonate, chloride,
sulphate, nitrate, and fluoride) were analysed as per the standard procedure (APHA 2012) shown in Table 2. Calcium, total hardness, chloride, and bicarbonate were estimated by titration method. Sodium and potassium were determined by flame photometry. Sulphate and nitrate are explored utilizing a spectrophotometer. Fluoride was determined by ion selective electrode. For the computation of analytical error, the total cations (Ca$^{2+}$ + Mg$^{2+}$ + Na$^{+}$ + K$^{+}$) and the total anions (HCO$_3^-$ + Cl$^-$ + SO$_4^{2-}$ + NO$_3^-$ + F$^-$) were used, which was observed to be ± 5% (Laxman et al. 2021) reflecting the reliability of the chemical data.

### Health risk assessment (HRA)

The risk assessment for human health exposure through drinking water pathway (Amiri and Berndtsson 2020; Brindha et al. 2020), in this study, chronic daily intake of
drinking water turned into an important publicity pathway for nitrate ($\text{NO}_3^-$) and fluoride ($\text{F}^-$). The non-carcinogenic risk from nitrate and fluoride (hazard index (HQ)), as per the US Environmental recommended standards, was calculated (USEPA 2004).

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

where ADD is defined as a dosage of daily $\text{NO}_3^-$ and $\text{F}^-$ (mg/kg/day), CGW is the concentration in water (mg/L), rate of humans is 2.5 L/day for adults, and 0.78 L/day for children marked with IR (ingestion rate), the contact period for adults is 70 and for children is 6 denoting with ED (exposure duration), EF is defined as exposure frequency in days or years, the average body weight (ABW) has been taken as 65 kg for adults and 15 kg for children. AET is defined as the average time (days: 25,550 and 2190 for adults and children).

The reference dosage is used as a measure of non-carcinogenic chronic hazards. Toxic effects are likely to occur when the exposure dose of the target contaminant exceeds the reference dosage, which is generally expressed as hazard quotient (HQ).

Fig. 3 Season wise rainfall distribution of the study area from 2013–2018 (in mm)

Fig. 4 Geology map of the study region showing sample locations
As per above equation, the reference dosage for oral intake of chronic exposure based on the nitrate and fluoride is 1.6 and 0.06 mg/kg/day, respectively (USEPA 2014). The total hazard index (THI) of non-carcinogenic substances, on the other hand, is calculated using the following equation.

\[
\text{THI} = \sum \text{HQ}
\]

The permissible limit of non-carcinogenic THI, according to the USEPA’s health risk assessment standard, is 1. If the THI is greater than 1, the non-carcinogenic risk of the contaminant is higher than the acceptable limit, but if the THI is less than 1, the non-carcinogenic risk is less than the allowable limit (USEPA 2014).

The following equation was calculating the cancerous risk (CR) for nitrate, based on the oral intake.

\[
\text{CR} = \text{ADD} \times \text{CSF}
\]

In the above equation, the cancerous risk through the oral intake and carcinogenic slope factor (CSF) value of nitrate is \(10^{-5}\) mg/kg/day, respectively (Darvishmotevalli et al. 2019; Toolabi et al. 2021).

The acceptable limit of cancerous risk is \(1 \times 10^{-6}\), if the CR is greater than \(1 \times 10^{-6}\) unacceptable limit (Briki et al. 2017; Toolabi et al. 2021).

### Results and discussion

#### General characteristic of groundwater chemistry

The groundwater chemistry analysed results of the study region which is recommended by the standard drinking water specifications (BIS 2012). The pH value of the groundwater a mean ranges from 7.71 and 7.57 in pre- and post-monsoon seasons (Table 3), which is indicating basic/alkaline conditions. The allowable limit of pH is 6.5 to 8.5 (BIS 2012) for drinking water in the study region which is within the limits. The mean values of EC 1284 µS/cm for pre-monsoon and the post-monsoon season were 922 µS/cm (Table 3).

#### Cations

The calcium values vary from 24 to 216 mg/L and 20 to 180 mg/L in pre- and post-monsoon seasons (Table 3). About 29% and 11% water samples are a non-acceptable limit of Ca\(^{2+}\) is 75 mg/L (BIS 2012). This is the dominance of plagioclase feldspars occurring in the host rock (Laxman et al. 2019). The magnesium values vary from 10 to 88 mg/L and 4.9 to 56 mg/L (Table 3). About 41% and 32% of groundwater samples are a non-acceptable limit of Mg\(^{2+}\) which is 30 mg/L prescribed for drinking water (BIS 2012).
The values of magnesium due to the dissolution and ion exchange of plagioclase feldspars minerals are in the origin of granitic terrain. The sodium and potassium values range between 33 and 288 mg/L, 2 and 10 mg/L in pre-monsoon and post-monsoon are 38–209 mg/L and 1–8 mg/L (Table 3), respectively.

**Anions**

The bicarbonate values vary from 135 to 498 mg/L and 114 to 412 mg/L in pre- and post-monsoon seasons (Table 3). The chloride values vary from 30 to 410 mg/L and 40 to 322 mg/L in both periods (Table 3). The non-acceptable level of Cl\(^{-}\) is 250 mg/L (BIS 2012) Indian standard specification which is specified for drinking water, about 16% and 11% of groundwater samples, respectively. The predominance of chloride levels in groundwater in the study region includes mineral weathering of granitic rock of apatite and other causes of municipal sewages, industrial effluents which contributes to the leachable in groundwater (Brindha and Kavitha 2015). Sulphate concentrations range from 6 to 76 mg/L and 6 to 78 mg/L, respectively. During both monsoon seasons, all groundwater samples had acceptable sulphate levels (200 mg/L) (BIS 2012). The study region dominance for cations in groundwater is Na > Ca > Mg > K and for anions it is HCO\(_3\) > Cl > NO\(_3\) > SO\(_4\) > F for in both seasons, respectively.

The TDS values vary from 87 to 1651 mg/L and 246 to 1536 mg/L (Table 3) in both monsoon seasons. About 73% and 57% of samples are a non-acceptable limit of TDS which is 500 mg/L (BIS 2012). The classification of groundwater samples is classified with the TDS values (Davis and Dewiest 1966; Freeze and Cherry 1979). As per the classification of the study region, around 82%

**Table 3 Statistics of groundwater chemistry of the study area**

| Variables      | Pre-monsoon season | Post-monsoon season | BIS (2012) |
|----------------|--------------------|---------------------|------------|
|                | Min | Max | Mean | % of samples | Min | Max | Mean | % of samples | Min | Max | Mean | % of samples |
| pH             | 7.24 | 8.20 | 7.71 | 0           | 6.91 | 8.30 | 7.57 | 0          | 6.5–8.5 |
| EC (µS/cm)     | 477 | 2664 | 1284 | –           | 388 | 1925 | 992 | –          | –     |
| TDS (mg/L)     | 305 | 1705 | 822  | 73          | 248 | 1232 | 635 | 57         | 500   |
| Ca\(^{2+}\) (mg/L) | 24  | 216  | 88   | 29          | 20 | 180  | 49  | 11         | 75    |
| Mg\(^{2+}\) (mg/L) | 10  | 88   | 35   | 41          | 4.9 | 56   | 26  | 32         | 30    |
| TH as CaCO\(_3\) (mg/L) | 119 | 860  | 310  | 4           | 70 | 676  | 228 | 4          | 600   |
| Na\(^+\) (mg/L) | 33  | 288  | 138  | –           | 38 | 209  | 103 | 2          | –     |
| K\(^+\) (mg/L)  | 2   | 10   | 4    | –           | 1  | 8    | 3   | –          | –     |
| HCO\(_3\)\(^-\) (mg/L) | 135 | 498  | 263  | –           | 114 | 412  | 212 | –          | –     |
| Cl\(^-\) (mg/L)  | 30  | 410  | 165  | 16          | 40 | 322  | 131 | 11         | 250   |
| NO\(_3\)\(^-\) (mg/L) | 12  | 396  | 140  | 88          | 8  | 260  | 82  | 63         | 45    |
| SO\(_4\)\(^2-\) (mg/L) | 6   | 76   | 30   | –           | 6  | 78   | 33  | –          | 200   |
| F\(^-\) (mg/L)   | 0.66 | 3.20 | 1.49 | 45          | 0.35 | 2.56 | 1.24 | 32         | 1.5   |
| Gibb’s (meq/L)  | 0.18 | 0.85 | 0.65 | –           | 0.23 | 0.82 | 0.65 | –          | –     |

Min = Minimum; Max = Maximum

**Table 4 Groundwater classifications on the basis of TDS (Freeze and Cherry 1979; Davis and Dewiest 1966) and TH (Sawyer et al. 2003)**

| Parameters | Range | Water type/Classification | % of groundwater samples pre-monsoon | % of groundwater samples post-monsoon |
|------------|-------|---------------------------|-------------------------------------|--------------------------------------|
| TDS (mg/L) | <1000 | Fresh                     | 82                                  | 75                                   |
| 1000–10,000 |      | Brackish                  | 18                                  | 25                                   |
| 10,000–100,000 |  | Saline                    | –                                   | –                                    |
| > 100,000 |      | Brine                     | –                                   | –                                    |
| TH (mg/L) | <75   | Soft                      | –                                   | –                                    |
| 75–150     |      | Moderately hard           | 18                                  | 16                                   |
| 150–300    |      | Hard                      | 39                                  | 48                                   |
| > 300      |      | Very hard                 | 43                                  | 36                                   |
Fig. 5  Spatial distributions of NO$_3^-$ concentration in the pre and post-monsoon seasons
are fresh and 18% are brackish water quality categories in the pre-monsoon season and 75% and 25% are fresh and brackish categories during the post-monsoon season, respectively (Table 4). The high value of TDS in the study region which is indicating the laxative and stomach problems will be affected (Ali and Ali 2018).

The TH as CaCO₃ values ranges from 119 to 860 mg/L and 70 to 676 mg/L (Table 3). Around 4% and 4% of the water samples are tested with a non-permitted limit of 600 mg/L for pre- and post-monsoon period (BIS 2012). The classified water samples are 18% moderately hard, 39% hard, and 43% very hard in the pre-monsoon and post-monsoon seasons, and 16%, 48%, and 36% correspondingly in the post-monsoon seasons (Sawyer et al. 2003) (Table 4).

**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, in addition, uses of nitrate on fertilizers and horticulture purposes. The excess nitrate in drinking water can be affected to human health (Zhang et al. 2018). Generally, NO₃⁻ concentration in natural groundwater is quite low, i.e. 10 mg/L (Stadler et al. 2008). The high concentrations of nitrate in groundwater in some semi-arid regions can be caused by natural processes such as production by near-surface bacterial oxidation of the ammonia (Amiri et al. 2021).

In both monsoon seasons, NO₃⁻ levels range from 12 to 396 mg/L, with a mean of 140 mg/L, and 8 to 260 mg/L, with a mean of 82 mg/L in the pre-monsoon and post-monsoon seasons (Table 3 and Fig. 5). As per the drinking water, specification of nitrate is 45 mg/L (WHO 2011), it is no health risk of humans, 45–100 mg/L causes health effects of children and adults and > 100 mg/L is very high health risk. As per the classification of nitrate, 12.5% and 37.5% of groundwater samples fall under the “No health risk class”, whereas 25% and 35.71% of groundwater samples fall under the “high health risk class” and 62.5% and 26.79% of groundwater samples fall under the “Very high health risk class” in the pre- and post-monsoon seasons, respectively (Fig. 6).

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. Fertilizers such as diammonium phosphate, urea, and superphosphate are commonly utilized and can seep into the subsurface. Because of the widespread use of nitrate fertilizers, nitrate can also drain away from soils, increasing the nitrate level in groundwater (Jalali 2011; Amiri et al. 2021). Thus, nitrate is gathered in water through various ways that incorporate shallow groundwater, domestic sewage, manures, agriculture, and horticultural wastes (Lokesh 2013).

**Spatial distribution of fluoride**

The fluoride concentration in drinking water limits is 1.5 mg/L (BIS 2012; WHO 2011), which is used as an excessive water effect in dental and skeletal fluorosis (Laxman et al. 2019). Fluoride spatial interpolation levels within the observed region vary from 0.66 to 3.20 mg/L, with a mean of 1.49 mg/L, and 0.35 to 2.56 mg/L, with a mean of 1.24 mg/L in both monsoons. The acceptable limit of 1.5 mg/L (BIS 2012) Indian Standards has been exceeded in about 45% and 32% of samples, respectively (Table 3 and Fig. 7). The high spatial interpolation of fluoride turned into delineated with a different pattern, shown in Fig. 8. The high fluoride distribution is identified in northern, southern, and south-western parts of the region; the alkaline nature of water increases the anionic exchange.

![Fig. 6 Nitrates concentration for risk evaluation for drinking water in pre and post-monsoon seasons](image)

![Fig. 7 Fluoride concentration for risk evaluation for drinking water in pre and post-monsoon seasons](image)
Fig. 8  Spatial distributions of fluoride concentration in the pre and post-monsoon seasons
in controlling the fluoride content in the aquifer regime (Saxena and Ahmed 2003).

The petro-graphical studies which consist of very fine-grained crystals of euhedral zircons with compositional zoning found as inclusions in the feldspar phenocrysts. Clusters of small apatite needles are very common within altered plagioclase and orthoclase grains. Fluorite grains are anhedral, less in abundance compared to biotite and apatite but these are coarse grained. The existence of fluoride-bearing minerals (fluorite, apatite, biotite, etc.) is commonly seen in this granite (Fig. 9). In the study region, some of the people are suffering from the primary source of fluoride exposure as it leads to various fluorosis health hazards.

**Hydrochemical facies**

The Piper chart has shown that the major fields of two triangular in the bottom (cation, anion) and a central diamond-shaped (Piper 1944). According to Piper, it is suggested that...
the dominance of groundwater chemistry includes alkaline earth, alkalis, weak acid, and strong acid. The Piper Trilinear classification of the study region is classified into six categories during pre- and post-monsoon seasons which are around Ca–HCO$_3$ of (18% and 25%) NaCl of (27% and 25%), mixed CaNaHCO$_3$ of (12% and 14%), mixed CaMgCl of (39% and 31%), CaCl of (2% and 5%) predominance of water type and 2% of NaHCO$_3$ only in pre-monsoon season shown in Fig. 10. According to the hydrochemical facies, enriching fluoride-bearing minerals in groundwater is a complicated process.

**Modified Gibb’s diagram**

The Gibbs diagram is employed for evaluating the effects of rock weathering, precipitation, and evaporation on water chemistry (Gibbs 1970). We used the modified Gibbs plot for prevailing the geochemical processes in the groundwater (Marandi and Shand 2018). The concentration of natural groundwater depends on several processes and factors viz., solubility and availability of minerals, exchange processes, geochemical environment, groundwater movement, residence time, and climatic conditions of the region. To understand the mechanism of groundwater the plot of TDS (mg/L) versus Na/(Na+ + Ca) (meq/L) were plotted (Fig. 11, left). The calculated Gibb’s ratio ranged from 0.18 to 0.85 meq/L and 0.23 to 0.82 meq/L with mean of 0.65 meq/L for pre- and post-monsoon season, respectively (Table 3). The figure shows almost all the groundwater samples fall into the rock-dominant zone for pre- and post-monsoon seasons indicating rock weathering and ion exchange plays a major role in changing the water chemistry (Amiri and Berndtsson 2020). Majority of the samples in the modified Gibbs plot (Fig. 11, right) also falls in the category of rock dominant. The current study reveals that rock dominance has a substantial impact on groundwater chemistry, demonstrating that the primary mechanism of weathering of rock-forming minerals is due to the wide-area covered by granitic gneisses. Inevitably, a few groundwater regions are prone to dissipation, demonstrating the prevalence of which reveals the impact of anthropogenic activity, due to the increase in sodium, chloride, and total dissolved solids concentrations (Saxena and Ahmed 2001; Satyanarayana et al. 2017).

**Statistical analysis**

The statistical analysis of the study region scatter plots like Ca$^{2+}$ + Mg$^{2+}$ vs HCO$_3^{-}$ + SO$_4^{2-}$ implies that silicate weathering is an important factor for the ions. It is likely that most of the dissolved silica in water originates from the chemical breakdown of silicates during weathering processes (Tiwari et al. 2016); Ca$^{2+}$ + Mg$^{2+}$ vs TC and Ca$^{2+}$/ Na$^+$ vs HCO$_3^{-}$/Na$^+$ plot (Fig. 12). Based on the above plots are shown that the pre-dominantly of granitic origin for the silicate minerals (plagioclase, hornblende, and biotite) are presence of ion exchange, hydrolysis, and precipitation to assess the groundwater chemistry in the study region (Laxman et al. 2019).
Factor analysis

Factor analysis of distinctive information sets has identified four components with eigenvalues higher than 1.0 which formally can be evaluated as statistically significant components by using the software of SPSS 23. Factor analysis is component rotated varimax to compare the variables from the study region were analysed groundwater samples and to distinguish the variables that impact each one. The factor

![Scatter plots showing (Ca^{2+} + Mg^{2+}) vs. (HCO_3^- + SO_4^{2-}), Na^+ + K^+ vs. (TC^+), Ca^{2+} + Mg^{2+} vs. (TC^+), HCO_3^-/Na^+ vs. Ca^{2+}/Na^+ for pre and post-monsoon seasons.](image-url)
loading is classified as strong, moderate, and weak corresponding to absolute loading values of $>0.75$, $0.75–0.50$, and $0.50–0.30$, respectively (Mor et al. 2006).

The factor analysis of the study region results obtained from the final rotated loading matrix in pre-monsoon season, the four-factor components which explain 80.43% of the cumulative variance (Table 5 and Fig. 13). Factor 1 signifies 52.58% of the variance with high positive loading on TH, Ca$^{2+}$, Cl$^-$, Mg$^{2+}$, EC and HCO$_3^-$, which indicates the mineral weathering, natural processes and the dissolution of alumino-silicate minerals like biotite, feldspar, calcite, muscovite and fluorite. These control the main chemical composition of the groundwater chemistry (Amiri and Berndtsson 2020). Factor 2 signifies 10.65% of the variance with high positive loading on F$^-$ and Na$^+$, which indicates that the dissolution of fluoride-rich minerals is leaching from groundwater which is favourable in an alkaline environment. Factor 3 signifies 9.20% of the variance with strong positive loading on K$^+$ and NO$_3^-$, in which predominance fertilizers and domestic sewage could be leached into the groundwater contamination. Factor 4 signifies 8.01% of the variance with high positive loading on SO$_4^{2-}$ and pH.

The four-factor analysis describes 80.10% of cumulative variance from the groundwater data in the post-monsoon season (Table 5 and Fig. 13), the four components

| Variables                  | Pre-monsoon |          |          |          | Post-monsoon |          |          |          |
|----------------------------|-------------|----------|----------|----------|-------------|----------|----------|----------|
|                            | PC1         | PC2      | PC3      | PC4      | PC1         | PC2      | PC3      | PC4      |
| pH                         | 0.100       | 0.020    | 0.229    | 0.679    | 0.100       | 0.677    | 0.032    | 0.039    |
| EC(µS/cm)                  | 0.744       | 0.453    | 0.375    | 0.271    | 0.897       | 0.295    | 0.199    | 0.116    |
| TDS(mg/L)                  | 0.744       | 0.453    | 0.375    | 0.271    | 0.897       | 0.295    | 0.199    | 0.116    |
| Ca$^{2+}$(mg/L)            | 0.920       | 0.099    | 0.086    | 0.056    | 0.459       | 0.800    | 0.084    | 0.014    |
| Mg$^{2+}$(mg/L)            | 0.807       | 0.175    | 0.357    | 0.146    | 0.541       | 0.721    | 0.163    | 0.204    |
| Na$^+$ (mg/L)              | 0.372       | 0.556    | 0.445    | 0.445    | 0.850       | 0.392    | 0.016    | 0.019    |
| K$^+$ (mg/L)               | 0.124       | 0.153    | 0.841    | 0.117    | 0.304       | 0.181    | 0.241    | 0.600    |
| HCO$_3^-$ (mg/L)           | 0.697       | 0.412    | 0.208    | 0.213    | 0.880       | 0.161    | 0.184    | 0.075    |
| Cl$^-$ (mg/L)              | 0.871       | 0.306    | 0.155    | 0.146    | 0.850       | 0.392    | 0.016    | 0.019    |
| NO$_3^-$ (mg/L)            | 0.301       | 0.427    | 0.676    | 0.146    | 0.501       | 0.327    | 0.390    | 0.177    |
| SO$_4^{2-}$ (mg/L)         | 0.028       | 0.050    | 0.162    | 0.734    | 0.064       | 0.082    | 0.931    | 0.015    |
| F$^-$ (mg/L)               | 0.132       | 0.860    | 0.108    | 0.156    | 0.006       | 0.083    | 0.122    | 0.883    |
| % of variance              | 6.84        | 1.38     | 1.20     | 1.04     | 6.67        | 1.62     | 1.08     | 1.04     |
| Cumulative % of variance   | 52.58       | 63.22    | 72.42    | 80.43    | 51.33       | 63.78    | 72.11    | 80.10    |

![Component Plot in Rotated Space](image)
| SampleNo | HQ-Fluoride (Adult) | HQ-Fluoride (Children) | HQ-Nitrate (Adult) | HQ-Nitrate (Children) | THI (NO$_3^-$ + F$^-$) (Adult) | THI (NO$_3^-$ + F$^-$) (Children) |
|----------|---------------------|-----------------------|-------------------|-----------------------|-------------------------------|---------------------------------|
| 1        | 1.26                | 1.71                  | 4.21              | 5.69                  | 5.47                          | 7.39                            |
| 2        | 1.88                | 2.54                  | 4.52              | 6.11                  | 6.40                          | 8.65                            |
| 3        | 1.57                | 2.12                  | 4.86              | 6.57                  | 6.43                          | 8.69                            |
| 4        | 1.08                | 1.46                  | 3.08              | 4.16                  | 4.16                          | 5.62                            |
| 5        | 0.64                | 0.87                  | 5.43              | 7.35                  | 6.07                          | 8.21                            |
| 6        | 0.79                | 1.07                  | 5.91              | 8.00                  | 6.71                          | 9.07                            |
| 7        | 0.85                | 1.14                  | 1.01              | 1.37                  | 1.86                          | 2.51                            |
| 8        | 0.60                | 0.81                  | 3.37              | 4.55                  | 3.97                          | 5.36                            |
| 9        | 0.64                | 0.87                  | 1.01              | 1.37                  | 1.65                          | 2.23                            |
| 10       | 0.77                | 1.04                  | 3.37              | 4.55                  | 4.13                          | 5.59                            |
| 11       | 0.74                | 1.01                  | 2.88              | 3.90                  | 3.63                          | 4.91                            |
| 12       | 1.29                | 1.75                  | 3.27              | 4.42                  | 4.56                          | 6.17                            |
| 13       | 1.03                | 1.39                  | 0.48              | 0.65                  | 1.51                          | 2.04                            |
| 14       | 0.90                | 1.21                  | 2.40              | 3.25                  | 3.30                          | 4.46                            |
| 15       | 1.21                | 1.63                  | 3.17              | 4.29                  | 4.38                          | 5.92                            |
| 16       | 0.66                | 0.89                  | 4.04              | 5.46                  | 4.70                          | 6.35                            |
| 17       | 0.93                | 1.26                  | 3.61              | 4.88                  | 4.54                          | 6.13                            |
| 18       | 0.77                | 1.04                  | 3.65              | 4.94                  | 4.42                          | 5.98                            |
| 19       | 0.51                | 0.69                  | 3.37              | 4.55                  | 3.88                          | 5.24                            |
| 20       | 0.64                | 0.87                  | 2.31              | 3.12                  | 2.95                          | 3.99                            |
| 21       | 0.65                | 0.88                  | 5.89              | 7.96                  | 6.54                          | 8.84                            |
| 22       | 1.74                | 2.36                  | 2.60              | 3.51                  | 4.34                          | 5.87                            |
| 23       | 1.15                | 1.56                  | 3.46              | 4.68                  | 4.62                          | 6.24                            |
| 24       | 0.77                | 1.04                  | 2.12              | 2.86                  | 2.88                          | 3.90                            |
| 25       | 1.03                | 1.39                  | 3.08              | 4.16                  | 4.10                          | 5.55                            |
| 26       | 1.23                | 1.66                  | 3.85              | 5.20                  | 5.08                          | 6.86                            |
| 27       | 1.24                | 1.68                  | 0.29              | 0.39                  | 1.53                          | 2.07                            |
| 28       | 0.50                | 0.68                  | 2.69              | 3.64                  | 3.19                          | 4.32                            |
| 29       | 0.42                | 0.57                  | 7.81              | 10.56                 | 8.24                          | 11.13                           |
| 30       | 0.42                | 0.57                  | 1.35              | 1.82                  | 1.77                          | 2.39                            |
| 31       | 0.56                | 0.76                  | 1.73              | 2.34                  | 2.29                          | 3.10                            |
| 32       | 0.77                | 1.04                  | 1.54              | 2.08                  | 2.31                          | 3.12                            |
| 33       | 0.65                | 0.88                  | 0.29              | 0.39                  | 0.94                          | 1.27                            |
| 34       | 0.77                | 1.04                  | 6.68              | 9.04                  | 7.45                          | 10.08                           |
| 35       | 1.44                | 1.94                  | 6.37              | 8.61                  | 7.81                          | 10.55                           |
| 36       | 1.03                | 1.39                  | 5.96              | 8.06                  | 6.99                          | 9.45                            |
| 37       | 0.88                | 1.19                  | 1.92              | 2.60                  | 2.80                          | 3.79                            |
| 38       | 0.78                | 1.06                  | 0.96              | 1.30                  | 1.74                          | 2.36                            |
| 39       | 1.15                | 1.56                  | 1.15              | 1.56                  | 2.31                          | 3.12                            |
| 40       | 1.03                | 1.39                  | 3.17              | 4.29                  | 4.20                          | 5.68                            |
| 41       | 1.03                | 1.39                  | 5.82              | 7.87                  | 6.84                          | 9.25                            |
| 42       | 1.15                | 1.56                  | 4.28              | 5.79                  | 5.43                          | 7.35                            |
| 43       | 0.64                | 0.87                  | 4.47              | 6.05                  | 5.11                          | 6.91                            |
| 44       | 0.42                | 0.57                  | 0.29              | 0.39                  | 0.71                          | 0.96                            |
| 45       | 1.03                | 1.39                  | 9.52              | 12.87                 | 10.54                         | 14.26                           |
| 46       | 0.90                | 1.21                  | 4.04              | 5.46                  | 4.94                          | 6.67                            |
| 47       | 1.28                | 1.73                  | 3.17              | 4.29                  | 4.46                          | 6.02                            |
| 48       | 1.22                | 1.65                  | 3.65              | 4.94                  | 4.87                          | 6.59                            |
| 49       | 1.41                | 1.91                  | 2.31              | 3.12                  | 3.72                          | 5.03                            |
of variance which explain 51.33%, 12.46%, 8.33%, and 7.99%. Here again, Factor 1 shows high positive loadings on EC, Na⁺, HCO₃⁻, Cl⁻, Mg²⁺ and NO₃⁻. Factor 2 signifies strong positive loading on TH, Ca⁺, Mg²⁺, and pH is high negative loading, which indicates that the mineral weathering of cations and anions dominated the groundwater quality (SubbaRao et al. 2020a). Factor 3 signifies strong positive loading on SO₄²⁻ which is due to the sulphate ions can be caused by the dissolution of evaporating minerals (gypsum, anhydrite, etc.) and even weathering of silicates (Tostevin et al. 2016). Factor 4 signifies strong positive loading on F⁻ and K⁺ showing higher dissolution of F⁻ in an alkaline environment, which is due to the geogenic sources.

Health risk assessment

The hazard quotient of the study region evaluated the non-carcinogenic for adults and children (Tables 6 and 7). In the pre-monsoon season, HQ-fluoride and HQ-nitrate for adults range from 0.42 to 1.88 and 0.29 to 9.52, with a mean of 0.93 and 3.31, for children, HQ-fluoride and HQ-nitrate through drinking water intake range from 0.57 to 2.54 and 0.39 to 12.87, with a mean of 1.26 and 4.48, respectively (Table 6). In the post-monsoon season, HQ-fluoride and HQ-nitrate through drinking water intake range from 0.22 to 1.64 and 0.19 to 6.25, with a mean of 0.79 and 1.96, for children, HQ-fluoride and HQ-nitrate range from 0.30 to 2.22 and 0.26 to 8.45, with a mean of 1.07 and 2.66, respectively (Table 7). The HQ as 1 for each element in terms of human health, according to the USA’s recommended criteria (USEPA 2014).

Table 6 and 7 shows the results of the total hazard index (THI) for adults and children. The THI values ranged from 0.71 to 10.54 and 0.42 to 10.54, with a mean of 4.24 and 2.76 for adults, 0.96 to 14.26 and 0.62 to 9.59 (with a mean of 5.73 and 3.73) for children, respectively, in pre- and post-monsoon seasons. The non-carcinogenic health risk results demonstrate that except sample locations 33 (0.94), 44 (0.67) and 53 (0.68), 33 (0.67), 44 (0.46) for adults in pre- and post-seasons, 44 (0.96) in pre-monsoon and 13 (0.92), 33 (0.91), 44 (0.62) in post-monsoon seasons for children exceeded the acceptable limit of 1 (THI adults > children) (Fig. 14). Based on the THI values, the HQ-nitrate and HQ-fluoride samples are higher than the acceptable limit, which indicates that nitrate contributes more to the non-carcinogenic risk than fluoride for adults and children in the study area. This also suggests that intake of nitrate contaminated drinking water can cause higher health risks than the fluoride to the residents in the study region (Amiri and Berndtsson 2020; Toolabi et al. 2021). The industrial development authority (IDAs) of Patancheruvu, Jeedimetla, Balanagar, Pashamailaram, Uppal, Katedan, Bollaram, and Medchal in these industrial corridors like steel, battery, petrochemical, pharmaceuticals, etc., has located in Hyderabad City. Furthermore, carcinogenic metals are hazardous to adults and children. Labourers and households near industrial complexes are thought to be exposed to higher concentrations of hazardous metals associated with groundwater than residents living further away from the industrial region. The carcinogenic and non-carcinogenic dangers to adults and children differ due to individual variances in body weight, respiration rate, and outdoor exposure. It may, however, pose a higher risk of carcinogenicity in children than in adults (Kushwaha et al. 2012).

Carcinogenic risk (CR) levels

In this study, the CR value of NO₃⁻ through the oral pathway was determined for adults and children in pre- and post-monsoon seasons using the approach recommended by the USEPA. NO₃⁻ carcinogenic risk estimates in
Table 7  Hazard Quotient (HQ) and Total Hazard Index (THI) for fluoride and nitrate in Adults and Children in the study area of post-monsoon season

| Sample No | HQ-Fluoride (Adult) | HQ-Fluoride (Children) | HQ-Nitrate (Adult) | HQ-Nitrate (Children) | THI (NO$_3^-$ + F$^-$) (Adult) | THI (NO$_3^-$ + F$^-$) (Children) |
|-----------|---------------------|------------------------|-------------------|----------------------|-------------------------------|----------------------------------|
| 1         | 1.64                | 2.22                   | 1.73              | 2.34                 | 3.37                          | 4.56                             |
| 2         | 1.14                | 1.54                   | 2.36              | 3.19                 | 3.50                          | 4.73                             |
| 3         | 0.89                | 1.20                   | 1.70              | 2.30                 | 2.59                          | 3.51                             |
| 4         | 0.76                | 1.03                   | 1.83              | 2.47                 | 2.59                          | 3.50                             |
| 5         | 0.56                | 0.76                   | 2.69              | 3.64                 | 3.26                          | 4.40                             |
| 6         | 0.63                | 0.85                   | 4.62              | 6.24                 | 5.24                          | 7.09                             |
| 7         | 0.59                | 0.80                   | 0.87              | 1.17                 | 1.46                          | 1.97                             |
| 8         | 0.56                | 0.76                   | 1.80              | 2.44                 | 2.37                          | 3.20                             |
| 9         | 0.97                | 1.32                   | 0.91              | 1.24                 | 1.89                          | 2.55                             |
| 10        | 0.67                | 0.91                   | 1.32              | 1.79                 | 2.00                          | 2.70                             |
| 11        | 0.62                | 0.83                   | 1.59              | 2.15                 | 2.20                          | 2.98                             |
| 12        | 1.26                | 1.70                   | 2.36              | 3.19                 | 3.61                          | 4.88                             |
| 13        | 0.45                | 0.61                   | 0.23              | 0.32                 | 0.68                          | 0.92                             |
| 14        | 0.63                | 0.85                   | 1.03              | 1.40                 | 1.66                          | 2.25                             |
| 15        | 0.97                | 1.32                   | 1.27              | 1.72                 | 2.25                          | 3.04                             |
| 16        | 0.62                | 0.83                   | 3.17              | 4.29                 | 3.79                          | 5.12                             |
| 17        | 0.85                | 1.14                   | 2.36              | 3.19                 | 3.20                          | 4.33                             |
| 18        | 0.97                | 1.32                   | 1.85              | 2.50                 | 2.83                          | 3.82                             |
| 19        | 0.62                | 0.83                   | 1.59              | 2.15                 | 2.20                          | 2.98                             |
| 20        | 0.60                | 0.81                   | 1.25              | 1.69                 | 1.85                          | 2.50                             |
| 21        | 0.51                | 0.68                   | 4.52              | 6.11                 | 5.03                          | 6.79                             |
| 22        | 0.97                | 1.32                   | 1.01              | 1.37                 | 1.98                          | 2.68                             |
| 23        | 0.72                | 0.97                   | 1.73              | 2.34                 | 2.45                          | 3.31                             |
| 24        | 0.60                | 0.81                   | 0.96              | 1.30                 | 1.56                          | 2.11                             |
| 25        | 0.64                | 0.87                   | 2.60              | 3.51                 | 3.24                          | 4.38                             |
| 26        | 0.50                | 0.68                   | 2.69              | 3.64                 | 3.19                          | 4.32                             |
| 27        | 1.31                | 1.77                   | 0.32              | 0.43                 | 1.63                          | 2.20                             |
| 28        | 0.59                | 0.80                   | 1.78              | 2.41                 | 2.37                          | 3.20                             |
| 29        | 0.42                | 0.56                   | 5.05              | 6.83                 | 5.46                          | 7.39                             |
| 30        | 0.56                | 0.76                   | 0.91              | 1.24                 | 1.48                          | 2.00                             |
| 31        | 0.77                | 1.04                   | 1.06              | 1.43                 | 1.83                          | 2.47                             |
| 32        | 0.93                | 1.26                   | 0.63              | 0.85                 | 1.55                          | 2.10                             |
| 33        | 0.48                | 0.65                   | 0.19              | 0.26                 | 0.67                          | 0.91                             |
| 34        | 0.63                | 0.85                   | 4.23              | 5.72                 | 4.86                          | 6.57                             |
| 35        | 1.58                | 2.13                   | 5.05              | 6.83                 | 6.63                          | 8.96                             |
| 36        | 0.78                | 1.06                   | 3.56              | 4.81                 | 4.34                          | 5.87                             |
| 37        | 0.72                | 0.97                   | 1.39              | 1.89                 | 2.11                          | 2.86                             |
| 38        | 1.17                | 1.58                   | 0.53              | 0.72                 | 1.70                          | 2.29                             |
| 39        | 0.64                | 0.87                   | 0.67              | 0.91                 | 1.31                          | 1.78                             |
| 40        | 0.97                | 1.32                   | 1.85              | 2.50                 | 2.83                          | 3.82                             |
| 41        | 0.72                | 0.97                   | 4.04              | 5.46                 | 4.76                          | 6.43                             |
| 42        | 1.04                | 1.40                   | 2.69              | 3.64                 | 3.73                          | 5.04                             |
| 43        | 0.59                | 0.80                   | 3.27              | 4.42                 | 3.86                          | 5.22                             |
| 44        | 0.22                | 0.30                   | 0.23              | 0.32                 | 0.46                          | 0.62                             |
| 45        | 0.85                | 1.14                   | 6.25              | 8.45                 | 7.10                          | 9.59                             |
| 46        | 0.60                | 0.81                   | 2.12              | 2.86                 | 2.72                          | 3.67                             |
| 47        | 1.21                | 1.63                   | 1.01              | 1.37                 | 2.21                          | 2.99                             |
| 48        | 1.00                | 1.35                   | 1.54              | 2.08                 | 2.54                          | 3.43                             |
| 49        | 1.27                | 1.72                   | 1.35              | 1.82                 | 2.62                          | 3.54                             |
groundwater samples via oral (ingestion) intake for adults/children are shown in Fig. 15. In the pre- and post-monsoon seasons, the CR values for NO$_3^-$ in potable water of all test stations for adults were in the range of $3 \times 10^{-6}$ to $9.5 \times 10^{-5}$ and $1.92 \times 10^{-6}$ to $6.3 \times 10^{-5}$, respectively, indicating that drinking water is unsuitable. Humans may be exposed to major health risks and poisoning if they drink drinkable water containing excessive levels of NO$_3^-$.

Methemoglobinemia is a well-known example of NO$_3^-$ toxicity in infants and pregnant women. NO$_3^-$ also causes respiratory problems in adults, as well as stomach cancer, thyroid gland hyperplasia, headaches and drowsiness, and multiple sclerosis (Ahada and Suthar 2018). In general, the carcinogenicity averages for NO$_3^-$ in children are $4.5 \times 10^{-5}$ and $2.66 \times 10^{-5}$ in the pre- and post-monsoon seasons, respectively. Other factors, such as geography, the amount of water consumed, and people’ lifestyle, may cause cancer in addition to the components in drinkable water.

### Conclusions

The pH is slightly alkaline to neutral in nature and ranges from 7.24 to 8.20 and 6.91 to 8.30 for pre- and post-monsoon season. The high fluoride concentrations are observed from south-western, northern, and central parts of the study region, with predominance of F$^-$-rich minerals present in the granitic terrain. The excess concentration of nitrate indicates that the fertilizers and domestic sewages could be leached into the subsurface. According to the Piper diagram classified categories during both seasons, Ca–HCO$_3^-$, NaCl and Mixed CaNaHCO$_3^-$ are the result of weathering and dissolution of rocks. In the pre- and post-monsoon season, the Gibbs diagram shows largely rock dominance, with only a few samples showing evaporation 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. Principal component analyses extracted all four-factor components rotated cumulative variance of 80.43% and 80.10% for pre- and post-monsoon season of the study region that is predominant of hydrogeochemical characteristics such as silicate weathering minerals, cation, and anthropogenic factors controlled to the groundwater contamination. The cumulative total hazard index (THI) of fluoride and nitrate for adult ranges from 0.71 to 10.54 and 0.46 to 7.10 and for children it ranges from 0.96 to 14.26 and 0.62 to 9.59 during pre- and post-monsoon season, respectively. Similarly, the carcinogenic risks of NO$_3^-$ for adults...
range from $3 \times 10^{-6}$ to $9.5 \times 10^{-5}$ and $1.92 \times 10^{-6}$ to $6.3 \times 10^{-5}$ in pre- and post-monsoon seasons, which shows that water is unsuitable for drinking. 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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Author’s contribution  LKD contributed to data acquisition and analyses, draft and conceptualization of manuscript. KKP contributed to literature review and writing manuscript. RD contributed to review and conceptualization. VH contributed to writing—review and editing and supervision. All authors read and approved the research paper.

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Availability of data and material  Data incorporated or analysed during this study region are included in the published article.

Declarations  

Conflict of interest  The authors declare that they have no conflicts of interest.

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