



Groundwater Quality Assessment and Thematic Spatial Mapping of Hisar District in Haryana (India)

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Abstract

Groundwater is a primary and precious resource for potable water in regions with low rainfall and a lack of surface water sources. The growth of such regions heavily depends on the availability of quality and quantity of groundwater. In the present study, the quality of groundwater with respect to its suitability for drinking purposes of Hisar district in Haryana (India) has been assessed by examining the physico-chemical parameters (pH, TDS, Ca^{2+} , Cl^{-} , TH, and F^{-}) of groundwater samples collected from 25 locations (rural and urban) during the pre- and post-monsoon periods. The Ca^{2+} and Cl^{-} ions concentration, and in turn total hardness (TH) at several studied locations exceeded the standard threshold limits of 75 mg/L, 250 mg/L and 300 mg/L, respectively, as prescribed by the Bureau of Indian Standards during the pre- and post-monsoon periods. The water quality categories based on water quality index (WQI) revealed that 4% and 24% of the sites had excellent (WQI = 0 to 25) and good (WQI = 26 to 50) water quality categories, respectively, during the pre-monsoon period, compared to 8% and 20% of the sites during the post-monsoon period. Seven sites (28%), representing a mix of urban and rural sites spreading all over the study area, have been in the unfit water quality category (WQI >100) during both the pre- and post-monsoon periods. Thematic spatial distribution maps – groundwater quality parameters and WQI, have also been generated using QGIS software to show the geographical distribution of water quality metrics in the studied area.

Keywords: Groundwater; Physico-chemical parameters; Water quality index (WQI); Thematic spatial distribution maps; QGIS

INTRODUCTION

Groundwater is a finite and restricted natural resource of potable water that is crucial for industrial, commercial, agricultural, drinking and domestic use, and the overall development of the region (Bouwer, 2000; Singh, 2009; Deswal and Deswal, 2017). The alterations in its quality are impacted by the chemical, physical, and biological environments through which it flows (Kumar *et al.*, 2006; Vasanthavigar *et al.*, 2010). Human activities have greatly altered the chemical and biological composition of groundwater, making it unsuitable for human consumption and other uses in many areas/regions (Gajendran and Thamarai, 2008; Shankar *et al.*, 2008; Gulgundi and Shetty, 2019; Tyagi *et al.*, 2020; Singh *et al.*, 2023). Due to increasing over-dependence on groundwater in most of the regions of India, several studies have been carried out for

specific water-stressed regions on their groundwater quality (Gupta *et al.*, 2009; Brindha *et al.*, 2014; Rao, 2018; Prajapati *et al.*, 2017; Ravish *et al.*, 2018; Ravish *et al.*, 2020).

As in the case of the majority of water-stressed areas of India, groundwater is being utilised as the main source of water for agricultural, industrial, commercial and domestic purposes, including drinking purposes in the entire Hisar district of Haryana in Northern India. The area of the Hisar district is represented by shallow aquifers and is prone to waterlogging. Furthermore, the groundwater is alkaline in nature and fresh to marginally and highly saline. So, it is essential to study the groundwater quality of aquifers during pre-monsoon and post-monsoon periods in the Hisar district.

In view of the above, the present study was carried out with the objective of assessing the groundwater quality of the Hisar district with respect to its suitability for drinking

purposes at various rural and urban locations. To achieve the said objective, the following assessments and thematic presentations have been carried out –

- assessment of groundwater quality with respect to selected drinking water quality parameters, namely pH, total dissolved solids, calcium, chlorides, total hardness and fluoride;
- computation of water quality index (WQI) using weighted arithmetic index method;
- variation in groundwater quality in pre- and post-monsoon periods;
- spatial distribution maps for groundwater quality metrics using QGIS software.

MATERIALS AND METHODS

Study Area Characteristics

The study area – district Hisar is situated in the western part of Haryana state in India. It is located between 28°56’00” - 29°38’30” N latitude and 75°21’12” - 76°18’12” E longitude (Fig. 1) and has a geographical area of 3,983 km². The general altitude of the study area varies from 203 to 225 m above mean sea level, and has a gentle slope in the south-west direction. Hisar district has been divided into nine community development blocks: Hisar-1, Hisar-2, Hansi-1, Hansi-2, Narnaund, Barwala, Uklana, Agroha and Adampur, with a total population of 1,743,931 having a population density of 438 people per sq. km. as per the census 2011, and the forecasted population of Hisar district in the year 2023 is 2,424,065 (Census, 2011).

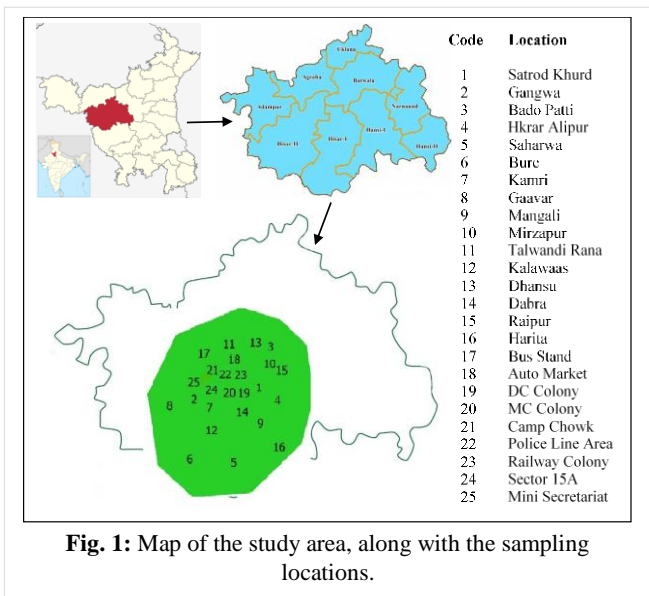


Fig. 1: Map of the study area, along with the sampling locations.

The study area falls in the Yamuna river sub-basin of the Ganga river basin, but there is no natural drainage in the area. The region falls in the alluvial Ghaggar-Yamuna plain, and its southern-western portions mark a gradual transition to the desert. It has a tropical monsoonal climate characterized as an arid type and categorised as ‘BSh’ according to the Köppen-Geiger classification (ClimateData, 2023). The major characteristics of climate are dryness, extremes of

temperature and scanty rainfall. The summers are very hot and the winters are fairly cold. The average temperature in Hisar is about 25.3°C. The normal annual rainfall is about 330 mm, out of which 283 mm (about 87 %) is received during the southwest monsoon season (June to September). The rainfall is unevenly distributed, and generally decreases from northeast to southwest in the district. The major soil types in Hisar district are sierozem, arid brown solonized and aeolian soils. The forest cover of the district is scanty and falls under the category of desert thorn. The Hisar district has a predominant unconsolidated alluvium geological formation of Quaternary age, having thickness varying from 228 to 310 m, and having sand and gravel as the major water-bearing formations.

Groundwater is being utilized as the main source of water for agricultural and drinking purposes in the entire study area. The groundwater level varies between 1.53 to 19.25 m below ground level (bgl) during pre-monsoon period and 0.43 to 18.30 m bgl during post-monsoon period with a seasonal fluctuation in water level in the range of -0.02 to 1.77 m and exhibited a rising and declining long-term water level trend during 2002-2011: fall in the range of -0.01 to -0.46 m/year, and rise in the range of 0.02 to 0.41 m/year (CGWB, 2013). As per report of CGWB (2013), Hisar-1 and Hisar-2 blocks fall in white category (safe); however, a declining trend of water levels has been observed in both these blocks of the district due to increasing water demand. In case the trend continued, the blocks may fall in the grey category (semi-critical or safe with caution for future development).

Sampling and Analysis

The cadastral map of the study area, along with the field data, was used in the course of this study. The cadastral map was digitised to generate a spatial database. Thereafter, using the map, the groundwater samples were collected from tube wells with depths ranging from 25 to 100 m in 1-litre capacity clean water plastic bottles from 25 different places located in the study area, marked in Fig. 1, before and after the monsoon season during the year 2022. The pre-monsoon period in the current study was considered from March to May, while the post-monsoon period was from October to November.

The samples were analysed for six critical water quality indicators, namely pH, Calcium (Ca²⁺), Chlorides (Cl), Fluoride (F), Total Hardness (TH), and Total Dissolved Solids (TDS), to conduct potability studies in accordance with BIS standards. On-site measurements were carried out for parameters – pH, EC, and TDS using portable testing equipment. Whereas, the other parameters were analysed off-site as per APHA protocol (APHA, 2012).

Water Quality Index

The water quality index (WQI), in general, shows the degree to which the water has been polluted. It is one of the methods that may be used to evaluate the quality of the water (Praveen and Roy, 2022). It is one of the most useful instruments for communicating information on the overall quality state of water to the user community as well as policy makers. Many different WQIs have been established and used to convert large datasets into a condensed and informative format,

making it easier to extract relevant information about the sample characteristics (Adimalla *et al.*, 2018).

In the present study, the weighted arithmetic method has been employed to calculate an index number, which is derived through the mathematical combination of relevant groundwater quality characteristics. In this approach, the index may be used to assess groundwater quality compared to its ideal condition (as defined by groundwater quality goals) and to offer insight into the degree to which water quality has been changed by human activity (Agrawal *et al.*, 2022). In addition, the index can also be used to evaluate water quality relative to its current state.

The following steps are considered for computing WQI by the weighted arithmetic method (Alemaw *et al.*, 2004; Singh and Hussain, 2016):

Computing weightage factor (W_i)

The weightage that is to be given to the different criteria of water quality is determined to be inversely proportional to the standards (S_i) that are suggested for the respective parameters (Eq. 1). The water quality parameters, together with their respective standards and unit weight (w_i), as per the Bureau of Indian Standards (BIS, 2012) are presented in Table 1.

$$W_i \propto 1/S_i \quad \text{or} \quad W_i = k/S_i \quad (1)$$

$$\text{Here, } k \text{ (a constant)} = 1/\left(\frac{1}{v_{s1}} + \frac{1}{v_{s2}} + \dots + \frac{1}{v_{sn}}\right) \quad (2)$$

Table 1: Weighting of parameters in units based on the BIS standards for drinking water.

Parameters	Standards	Unit Weight (w_i)
pH	6.5 – 8.5	0.0248
Total Hardness	300	0.0007
Chloride	250	0.0008
Fluoride	1	0.1404

Water quality rating (Q_i)

The following algorithm (Eq. 3) is used to calculate an overall rating for each item/attribute.

$$Q_i = \left[\frac{(V_a - V_i)}{(S_i - V_i)} \times 100 \right] \quad (3)$$

where V_a and V_i are the actual and ideal values of the water quality parameters of the sample, respectively. The optimal value for every parameter is zero, with the exception of pH and dissolved oxygen.

WQI computation

A WQI is simply a grouping of a variety of characteristics that have been used to evaluate the overall quality of water. A weightage factor (W_i) that is relevant to the relevance of the test to water quality is then multiplied by the numerical value of the quality rating (Q_i). An overall WQI is then estimated by adding all of the individual results that are obtained from the test.

$$WQI = \sum Q_i W_i \quad (4)$$

The water quality scale with reference to WQI used in the present study is presented in Table 2.

Table 2: Water Quality Scale with reference to WQI.

S. NO.	WQI	Water Quality Classification
1.	0 – 25	Excellent
2.	26 – 50	Good
3.	51 – 75	Poor
4.	76 – 100	Very poor
5.	> 100	Unfit and unsuitable for drinking

Thematic Spatial Maps

The geo and attribute (water quality metrics) database has been combined/merged to generate spatial distribution thematic maps by using GIS models in several studies of this nature (Kundu *et al.*, 2001; Alemaw *et al.*, 2004; Selyam *et al.*, 2014; Halder *et al.*, 2020). The geo database includes the longitude and latitudes of the groundwater sample sites/locations, which were measured using the GPS during sampling. The attribute database for the present study is constructed using the water quality metrics of the examined groundwater samples. The water quality metrics used to generate the thematic spatial maps include individual water quality parameters (pH, Ca^{2+} , Cl^{-} , F^{-} , TH, and TDS), and the water quality index (WQI). In this study, the IDW raster interpolation method in QGIS software was used to generate the thematic spatial maps.

RESULTS AND DISCUSSION

The results of the study are presented and discussed systematically under two major sections. In the first section, the groundwater physico-chemical parameters have been analysed at individual sites and spatially in the study area during the pre- and post-monsoon. Thereafter, in the second section, the overall groundwater quality in terms of WQI has been analysed and discussed.

Analysis and Spatial Variations of Groundwater Physico-chemical Parameters

The results of the physico-chemical analysis of the groundwater in the study area during the pre- and post-monsoon seasons are presented graphically for individual parameters along with their thematic spatial maps and discussed systematically.

pH variations

The changes in pH levels were caused by an increase or reduction in the amount of biological activity caused by humans or other organisms. During pre-monsoon, the pH varied from 6.8 to 7.4, and post-monsoon, it varied from 7.1 to 8.0, as shown in Fig. 2. The vast majority of the study's locations had an alkaline propensity. Both in the pre- and post-monsoon sampling, the values of pH were between the desired levels (6.5 to 8.5) as per BIS standards. However, pH increased during the post-monsoon period due to recharge of groundwater due to rainfall. Fig. 2 also shows the spatial map of pH during pre- and post-monsoon periods in the study area. It is observed that during the post-monsoon, the pH in major parts of the area increased to the range of 7.0 – 7.5, and above 7.5 in the southern parts. Unlike the pre-monsoon period, no part of the study area has a pH less than 7.0 post-monsoon.

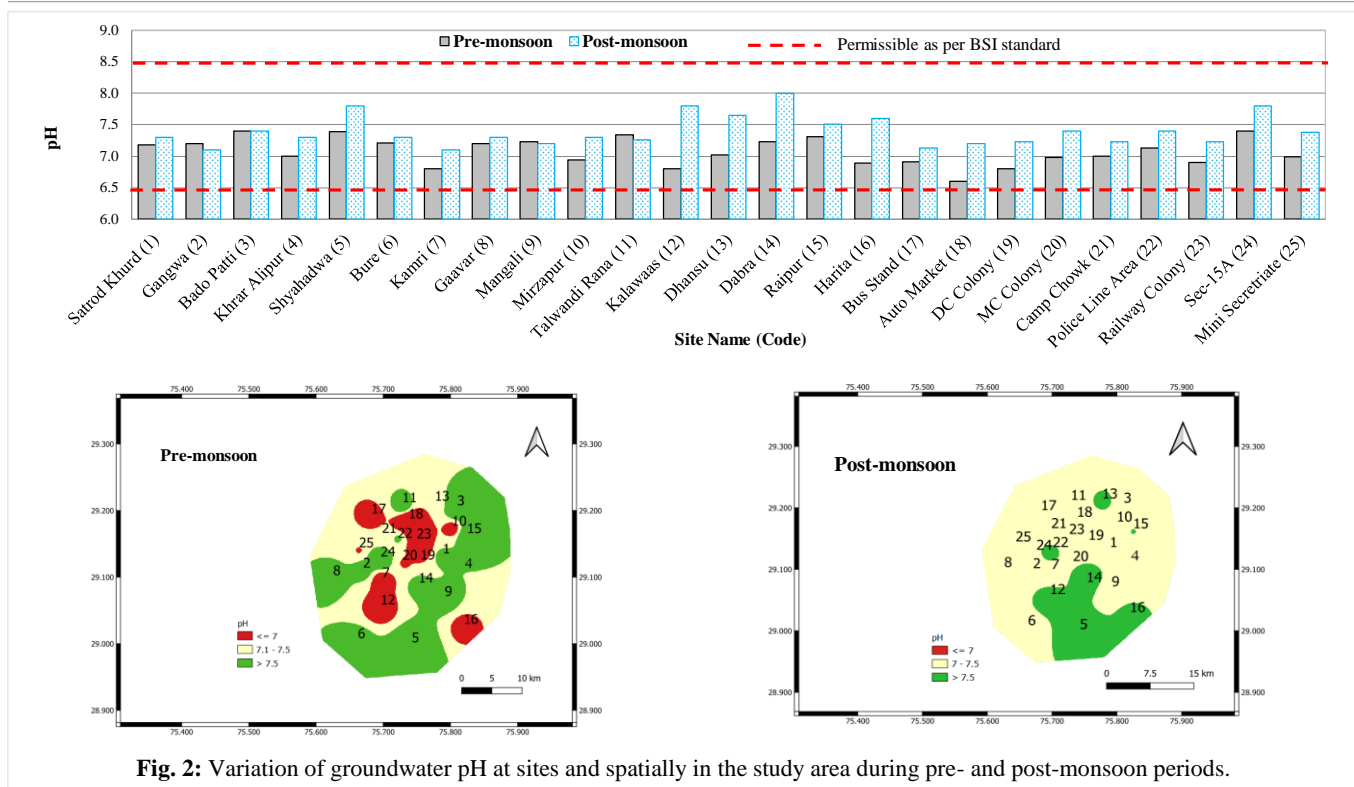


Fig. 2: Variation of groundwater pH at sites and spatially in the study area during pre- and post-monsoon periods.

Total dissolved solids (TDS) variations

Typically, groundwater sources have higher TDS compared to surface water sources. In the studied area, the TDS ranged between 85 to 970 mg/L during the pre-monsoon period, and between 110 to 800 mg/L during the post-monsoon period (Fig. 3). Most of the sites have TDS within the BIS recommendations of 500 mg/L, barring five sites (code: 5, 6, 21, 24 and 25). The pre-monsoon samples have generally

shown high TDS, possibly due to water concentration through evaporation. Conversely, post-monsoon TDS values at all sites were generally lower due to the dilution of water with rainwater. High TDS water is considered unsuitable for boilers and thus restricted to industrial usage. Fig. 3 also shows the spatial map of TDS during pre- and post-monsoon periods in the study area. It is observed that there was no significant spatial variation in TDS in groundwater during the pre- and post-monsoon periods in the study area.

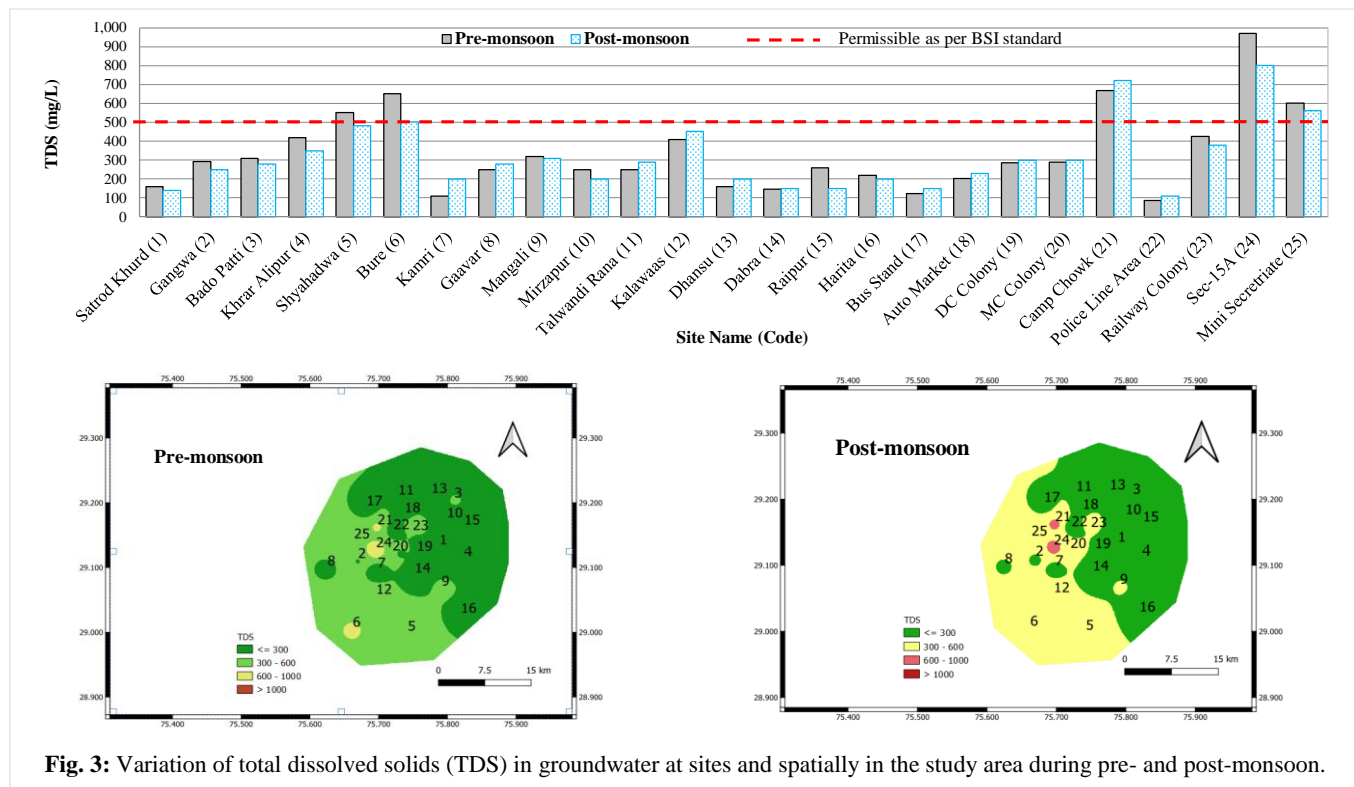


Fig. 3: Variation of total dissolved solids (TDS) in groundwater at sites and spatially in the study area during pre- and post-monsoon.

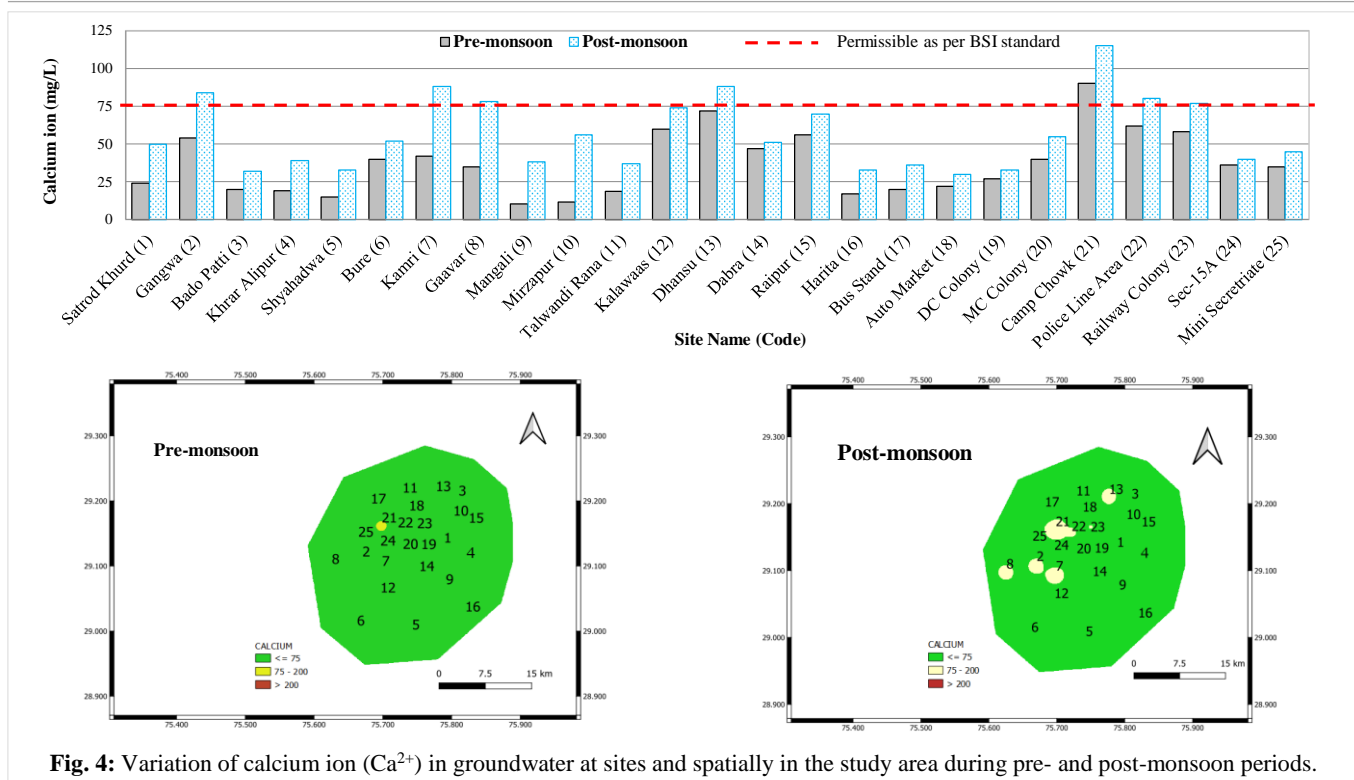


Fig. 4: Variation of calcium ion (Ca²⁺) in groundwater at sites and spatially in the study area during pre- and post-monsoon periods.

Calcium ion (Ca²⁺) variations

During the pre-monsoon period, the calcium ion concentrations at the sample sites ranged from 11.5 to 90.0 mg/L, which significantly increased in the range of 30.0 to 115.0 mg/L after the monsoon period (Fig. 4). Calcium concentrations were lower than the threshold of 75 mg/L at all the locations during the pre-monsoon period, except at site 21. However, post-monsoon, the calcium concentration was higher than the threshold of 75 mg/L at eight sites. The spatial

expansion of calcium ion concentration above 75 mg/L in the study area (in small pockets) during the post-monsoon period is clearly demonstrated in the thematic maps (Fig. 4). This can be attributed to the presence of a significant quantity of limestone in the study area, which leads to increased solubility of calcium ions.

Chlorides (Cl¹⁻) variations

The range of chloride concentrations in the pre-monsoon The

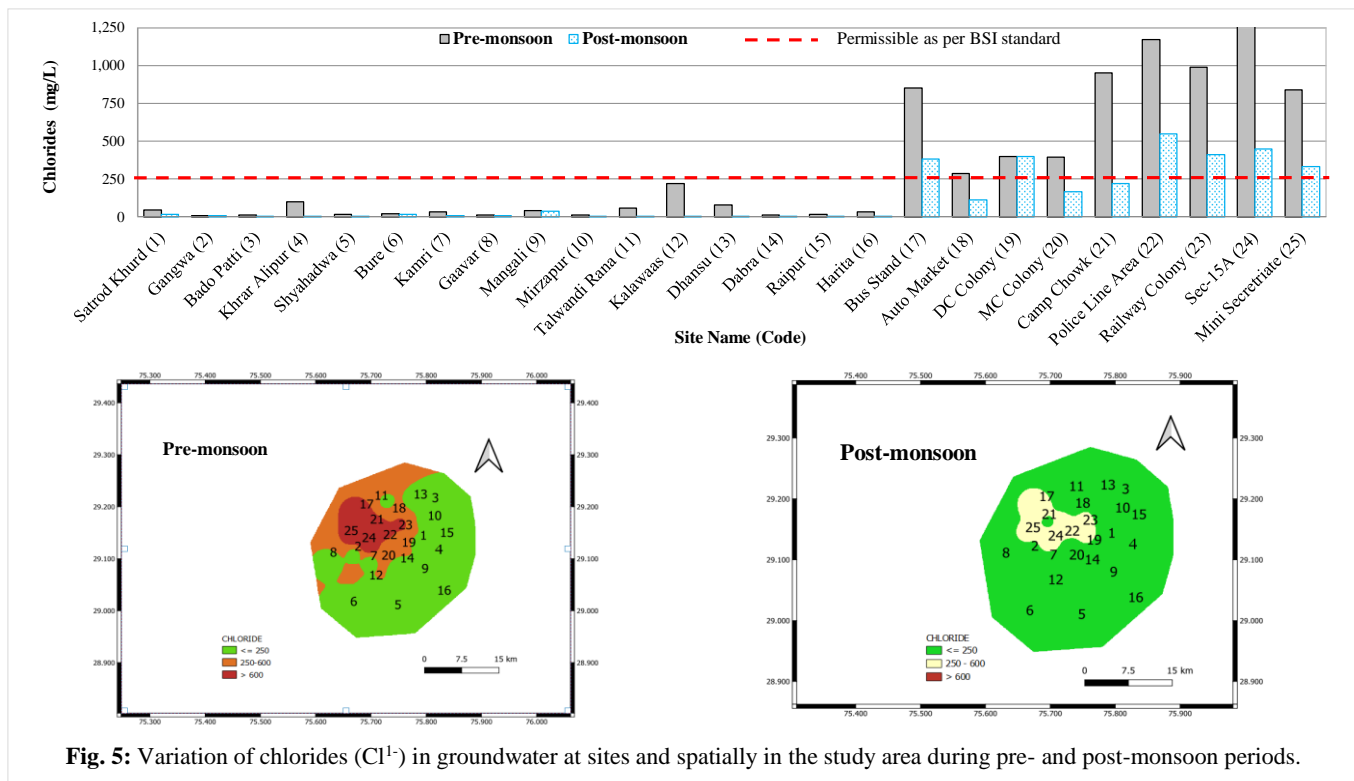


Fig. 5: Variation of chlorides (Cl¹⁻) in groundwater at sites and spatially in the study area during pre- and post-monsoon periods.

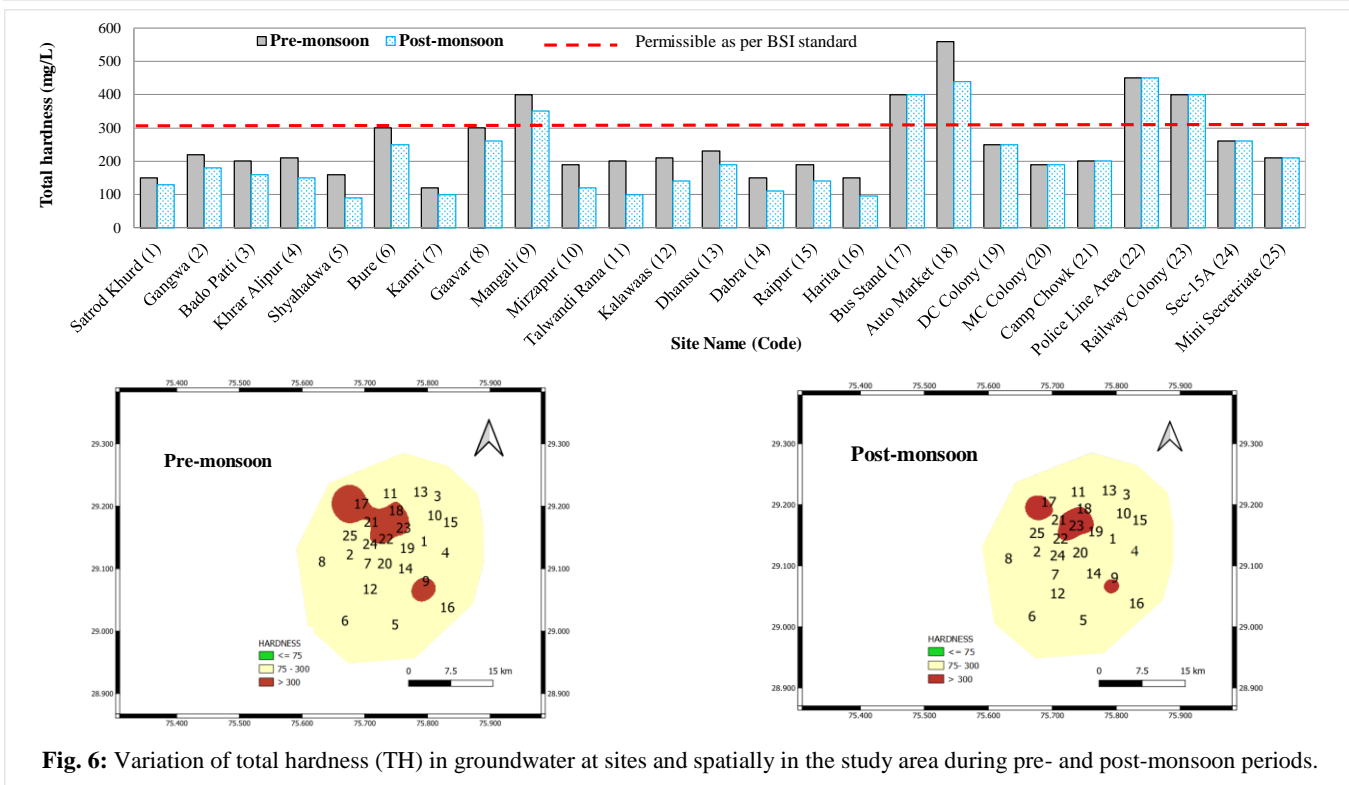


Fig. 6: Variation of total hardness (TH) in groundwater at sites and spatially in the study area during pre- and post-monsoon periods.

Season was from 8 to 1,330 mg/L; whereas, in the post-monsoon season, it decreased significantly at all sites and was observed to be between 6 to 550 mg/L (Fig. 5). Before the monsoon, nine sites in the north-western parts of the study area had chloride concentrations higher than the recommended level of 250 mg/L by BIS standards. In the post-monsoon period, the chloride concentration at three sites (code: 18, 20 & 21) out of these nine sites lowered to within the recommended levels. The spatial expansion of lowered

chloride concentration in the study area during the post-monsoon period is clearly demonstrated in the thematic maps (Fig. 5). The use of bleaching goods by people who live close to bore wells and other anthropogenic activities, like using septic tank effluents, is also attributable to the higher levels of chloride in the groundwater in the study area.

Total hardness (TH) variations

During the pre-monsoon season, the total hardness measured

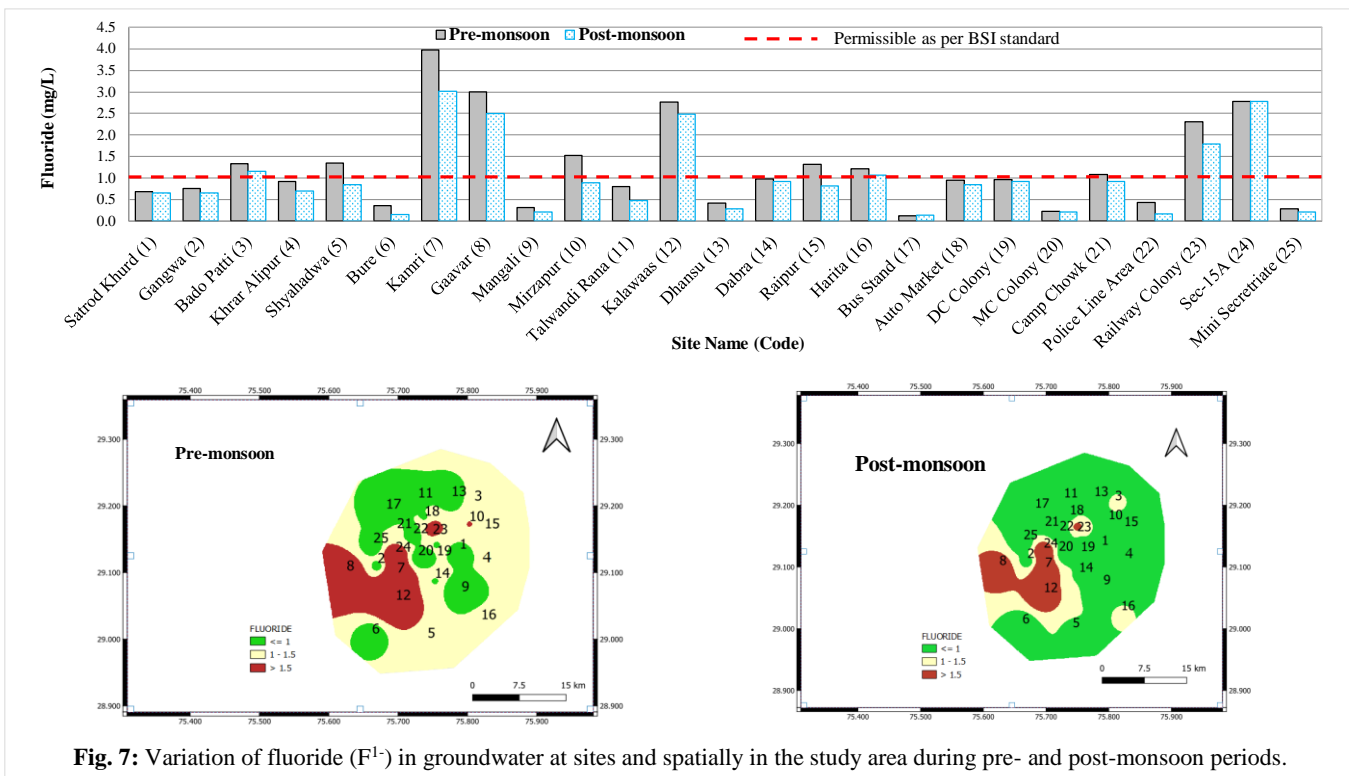


Fig. 7: Variation of fluoride (F¹⁻) in groundwater at sites and spatially in the study area during pre- and post-monsoon periods.

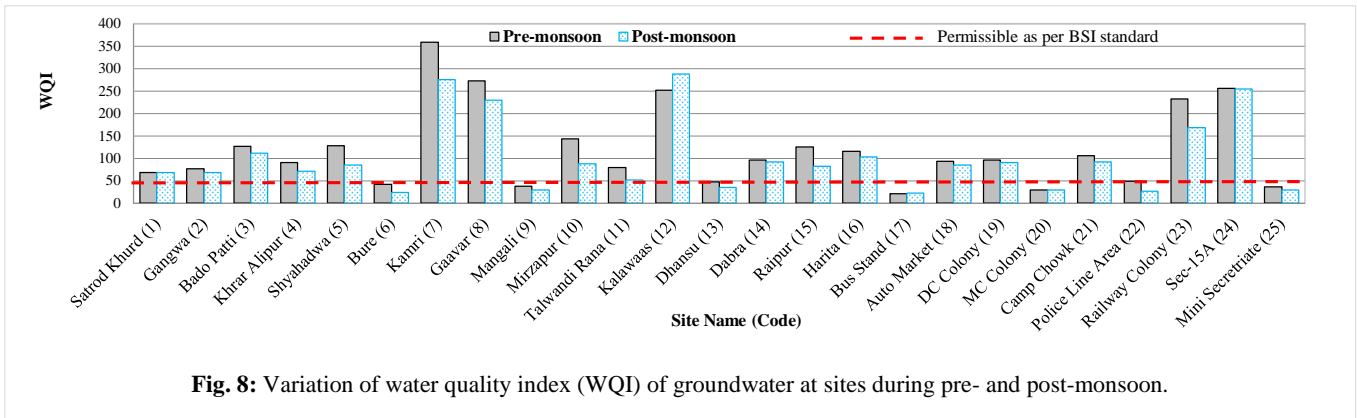


Fig. 8: Variation of water quality index (WQI) of groundwater at sites during pre- and post-monsoon.

Across all sites ranged from 120 to 560 mg/L; while in the post-monsoon season, the values declined at all sites and ranged from 90 to 440 mg/L. At five sites (code: 9, 17, 18, 22 & 23) the water hardness exceeded the BIS standard threshold of 300 mg/L, during both the pre-and post-monsoon seasons (Fig. 6). This higher hardness can be attributed to the elevated calcium content at these locations. Total hardness concentration has been fairly uniform spatially in the study area, and below 300 mg/L during pre- and post-monsoon periods, except three small pockets as depicted in the thematic maps (Fig. 6). It is important to note that the presence of hardness does not pose any direct harm to the human body. However, water with a hardness concentration exceeding 300 mg/L may lead to the accumulation of scale in the water distribution system and also require increased soap usage in laundry.

Fluoride (F¹⁻) variations

Fluoride is a natural contaminant of water that is commonly found in groundwater due to geological formations. Fluoride concentrations at the sampled sites in the study area varied from 0.12 to 3.98 mg/L during the pre-monsoon season, and from 0.15 to 3.02 mg/L during the post-monsoon season (Fig. 7). The thematic maps of fluoride revealed that fluoride concentration is higher in south-west parts and lower in north-central parts of the study area (Fig. 7). Although the fluoride concentration declines during post-monsoon period; however, it remains higher than the permissible limits of 1.0 mg/L both during the pre- and post-monsoon periods at about half of the sites. Fluorosis of the teeth and bones can be caused by excessive fluoride exposure.

Water Quality Index (WQI) of Individual Sites and Spatial Spread in the Study Area

WQI has been utilized widely to determine the water quality by assessing the level of impurities present (Kumari *et al.*, 2020). The results indicated that the WQI values ranged from 20.84 to 358.12 for the pre-monsoon season, and 22.47 to 288.40 for the post-monsoon season (Fig. 8). The graphs generated using these values indicate a minor shift in the WQI values between the two seasons.

Table 3: Classification of sites based on water quality category.

Water Quality Category	% Representation of Sites based on WQI	
	Pre-monsoon	Post-monsoon
Excellent	4	8
Good	24	20
Poor	4	16
Very poor	24	28
Unfit and unsuitable for drinking	44	28

The water quality category based on the WQI range of the studied sites/locations is presented in Table 3. During the pre-monsoon period, 4% and 24% of the studied locations had excellent and good water quality categories, respectively; whereas, the rest of the sites fell under poor (4%), very poor (24%), and unfit and unsustainable for drinking (44%) categories. During the post-monsoon period, 8% and 20% of the studied locations had excellent and good water quality

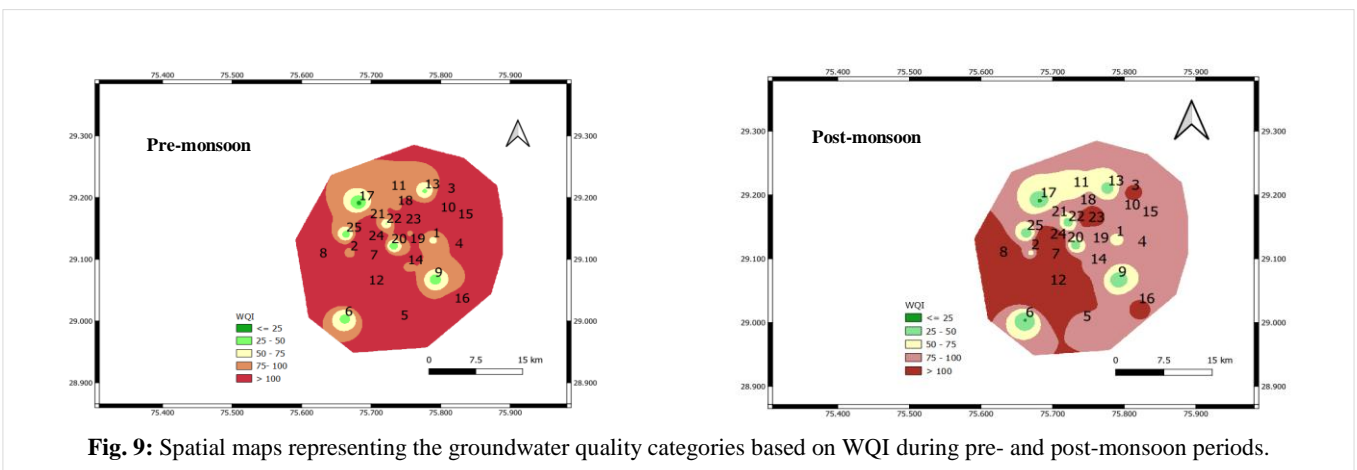


Fig. 9: Spatial maps representing the groundwater quality categories based on WQI during pre- and post-monsoon periods.

categories, respectively; whereas, the rest of the sites fell under poor (16%), very poor (28%), and unfit and unsustainable for drinking (28%) categories. Only one site – Bus Stand (17), which is an urban site, has excellent water quality (WQI = 0 to 25) during pre- as well as post-monsoon periods. Seven sites – Kalawaas (12), Bao Patti (3), Railway Colony (23), Sec-15A (24), Gaavar (8), Harita (16), and Kamri (7), representing a mix of urban and rural sites spreading all over the study area, have been in unfit water quality category (WQI >100) during both the pre- and post-monsoon periods.

For better presentation and visualization, the spatial maps are generated to depict the water quality categories of the study area during pre- and post-monsoon periods, as shown in Fig. 9. The Green shaded region indicates ‘excellent’ quality of groundwater (WQI<25) and the light green shaded region indicate ‘good’ quality of groundwater (25<WQI<50). Yellow, brown and wine-red regions indicate ‘poor’ (50<WQI<75), ‘very poor’ (75<WQI<100) and ‘unfit and unsuitable’ (WQI>100) quality of groundwater for drinking purposes.

Conclusion

The study of groundwater quality in Hisar district revealed marked seasonal and spatial variations affecting its potability. While pH and TDS were generally within BIS limits, elevated concentrations of calcium, chloride, total hardness, and fluoride frequently exceeded standards, with fluoride posing persistent health concerns. WQI analysis showed that a majority of sites ranged from poor to unfit, though slight improvements occurred post-monsoon. Thematic spatial mapping effectively identified contamination hotspots, providing a basis for targeted interventions. Continuous monitoring, public awareness, and sustainable management practices are essential to safeguard groundwater resources and ensure safe drinking water in the region.

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Conflict of Interest

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission, and redundancy has been completely observed by the authors.

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