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RESEARCH PAPER

Geospatial evaluation of groundwater quality in an industrialized district of Haryana, India, using an integrated approach

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Abstract

Gurugram district is undergoing a phase of rapid industrialization and urbanization leading to immense increase in anthropogenic activities. Thus, it is imperative to identify the possible impacts of these activities on human and environmental health. Besides evaluating the groundwater quality, delineation of the problematic zones and categorizing parameters that may pose severe health risks to residents, is equally important. For a holistic assessment of this area, groundwater quality results were integrated with pollution indices, multivariate statistics and geospatial technology to give a true indication of the potability of water. Various water quality indices were taken to comparatively evaluate the water quality results. Based on the groundwater quality index (GWQI), 47.62% of the samples were identified as of good quality, while 52.38% exhibited poor quality. Another specific index, namely, Heavy metal pollution index (HPI), showed that 33.33% of the samples had medium and 66.67% had a high level of pollution. Besides, these two indices degree of contamination (C_d), was also used to check for the contamination levels, which demonstrated that a significant number of samples (90.48%) were highly contaminated posing significant health hazards to the local population. Thereafter, PCA was done to identify the primary influencers of groundwater geochemistry which turned out to be hardness, calcium, magnesium, dissolved solids, lead, nickel and fluoride. The results so obtained, were mapped using geospatial technology that depicted that groundwater quality in the west and southeast zones was severely affected. The tangible results of the study are expected to help government authorities and decision-makers to devise a defined strategy for future health risk assessment and further assist in protecting this vulnerable resource.

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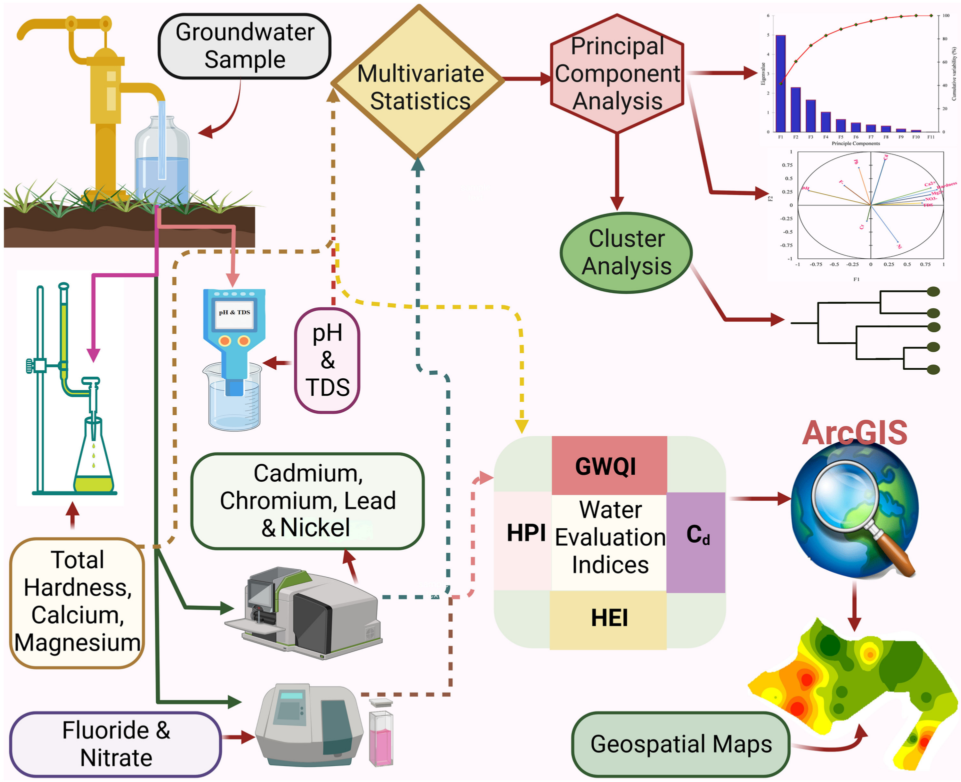
Graphical abstract



Keywords Environmental health · Geospatial technology · Groundwater quality · Health risk · Pollution indices

Introduction

Groundwater is one of the most vital resources provided by nature for the survival of life on earth. It is estimated that approximately 50% of domestic and 40% of the industrial demand is satisfied by the groundwater all around the globe (Kubicz et al. 2021). However, in India 50% of the urban and 80% of the rural population depends on groundwater for their domestic needs (Krishan et al. 2023). The stress on groundwater is ever increasing due to rising population, insufficient availability of surface water resources and uneven rainfall patterns (Dhillon and Mamta 2023). Unregulated extraction coupled with rapid increase in industrial and residential discharge of effluents has not only degraded the groundwater quality (Central groundwater board 2018), but has also increased the number of areas with depleted water tables (Adhikary et al. 2010).

Currently, deterioration of groundwater quality has become an urgent concern due to the intrinsic exposure of aquifers to various contaminants (Tomer et al. 2019), especially in the urban and peri-urban areas, which witness heavy industrial activities. Thus, monitoring groundwater becomes mandatory for proper management of these resources in order to meet the goal of "Clean Water and Sanitation", introduced in 2015 by the United Nations as SDG 6 (Sustainable Development Goals). Evidently, the prime focus of this SDG is to improve water quality by minimizing pollution and managing water contaminants effectively (Swain et al. 2022). Prima Facie, SDG 6 first objective is to evaluate the physicochemical characteristics of water resources to determine its suitability for drinking and other purposes (Rezaei et al. 2019). Consequently, this leads to generation of humongous amount of data related to each of the parameter analyzed, that needs to be interpreted using various analytical tools.

Various approaches have been employed worldwide to evaluate and better understand complex data sets of water quality parameters (Bharti and Katyal 2011), interpretation of which can sometimes become quite demanding (Bhuiyan et al. 2016). Here comes the role of 'Pollution indices' that efficiently communicate water quality information to decision-makers by consolidating this exhaustive data (Katyal et al. 2012) in comprehensive numbers taking into consideration all hydro geochemical parameters (Tomar et al. 2016). Simultaneously, it must be mentioned that indices provide superior results when analyzed through multivariate statistical tools (Bhuiyan et al. 2016). The data so generated, is depicted on maps using geospatial methods, which clearly indicates the spatial distribution and migration of pollutant in aquatic resources. Suffice to say, that combining vulnerability indices, multivariate analysis, and geospatial technologies (GIS) provides a holistic solution giving an insight into complex hydrochemistry of the area (Roy et al. 2021). This combination can determine the status of groundwater quality, predict the dominant processes influencing its chemistry, and demonstrate its spatial variability with a high degree of precision.

Researchers have generally utilized clubbing, any two of the above-mentioned integrated approach to measure contamination levels and categorize water quality in aquifers. To give a further insight into the current status of the research, dimensions pertaining to the related work has been elucidated in defined sections of International, National and Local level hereafter.

A study by Boum-Nkot et al. (2023) used heavy metal pollution indices to conclude that 90.5% of water samples taken from Douala city in Sub-Saharan Africa were poor and unsuitable for drinking. El-Kholy et al. (2022) used pollution indices and multivariate statistics to investigate water quality in north-western Egypt, and found that heavy metal concentrations in the samples exceeded the permissible limit. Hyarat et al. (2022) evaluated groundwater quality in the Amman-Zarqa area of Jordan using WQI and multivariate analysis, and revealed that it varied from excellent to poor, with anthropogenic activities significantly impacting the northern region. Furthermore, Alfaifi et al. (2021) used different water quality and pollution indices along with multivariate statistical tools to conclude that nearly 48% of the water samples from Jazan Province of Saudi Arabia were unsuitable for domestic and agricultural use.

Among Asian countries, India is a nation where the degradation of groundwater resources has attracted the attention of numerous researchers. For instance, by combining water quality index with geospatial technology, Ram et al. (2021) reported that groundwater quality in Bundelkhand region of Uttar Pradesh was rapidly deteriorating. Alam et al. (2022) in Manipur used WQI and multivariate statistics to conclude that over 50% of the water samples were not safe for drinking. Based on water pollution index and multivariate analysis, Bhatt et al. (2021) discovered that nearly 23% of the underground water samples from Arwal and Jehanabad districts, Bihar were moderately to severely polluted. Similarly, Ravindra et al. (2023) used statistics and WQI, to demonstrate that all the samples from Guntur district, Andhra Pradesh, exhibited either poor or very poor quality that could be attributed to high salinity and hardness.

In the Indian subcontinent, Haryana state is experiencing rapid industrial growth and infrastructural development (Ravish et al. 2019). Consequently, a severe decline in the water table and degradation of water quality is a significant concern that needs to be monitored regularly. Furthermore, high concentration of toxic substances in water poses a severe health risk to consumers, including humans, wildlife and biodiversity. Despite this, most water quality studies in the state focus on a few or more physicochemical properties, due to which the severity of toxic heavy metal contamination remains unidentified. In the Beri block of the Jhajjar district, the multivariate statistical approach was applied by Panghal and Bhateria (2021) to determine that the groundwater quality in the area was severely deteriorating. Ravish et al. (2020) conducted a similar assessment in Yamunanagar and Ambala districts concluding that the groundwater was unfit for human consumption without treatment. Besides multivariate analysis, Panghal et al. (2022) also used WQI to determine groundwater quality in the Bhiwani district and found it unsuitable for drinking. Furthermore, Masood et al. (2022) also used water quality indices and geospatial mapping to highlight the vulnerability of groundwater aquifers to contamination in the Mewat district, Haryana.

The current research region is a heavily industrialized peri-urban area in Gurugram District, where groundwater is the primary water source for drinking, agricultural and industrial operations. Gradually over years, the groundwater level has decreased by 82% from 2006 to 2016, from 20 to 36 m below ground level (Central Groundwater Board 2017). Because of which the area is facing sever water crises and is categorized as “over exploited”. Thus, constant assessment of water quality and quantity in this region is crucial for the well-being of environment and the people. In spite of this, only a few studies have attempted to evaluate groundwater quality in the chosen study area. For instance, In Gurugram city, Panghal et al. (2023) used WQI and statistical tools to highlight the unsuitability of groundwater for drinking purposes due to high concentration of heavy metals. Kumari and Rai (2020) used the WQI and geospatial approach in the Gurugram division and concluded that groundwater resources in nearly 45.31% of the region were unsuitable for drinking and irrigation. In the Faridabad and Gurugram districts, Swain et al. (2022) used geospatial models and statistical approach to conclude that nearly 36% of the samples analyzed were unfit for drinking. Tiwari et al. (2023) used GWQI to conclude that major area of Gurugram had poor groundwater quality. Yadav et al. (2023) used WQI and geospatial technology to conclude that groundwater near Bandhwari landfill site, Gurugram was unfit for domestic use.

It is important to emphasize here that all the above-mentioned studies, both international and national, integrate only two approaches rather than clubbing three approaches of physiochemical characterisation, multivariate analysis and final mapping, suggested and used in this research paper.

Generally, the research conducted in the study region till date is limited to determining the concentrations of major ions in water, ignoring the heavy metal contamination and its detrimental effects. Thus, a comprehensive picture of groundwater contamination status is not available in the region. Moreover, these studies are not being conducted at a pace that is compatible with the rapid rate at which Gurugram is urbanizing and industrializing. In light of this, it was decided to select an area within a radius of 5 km from major industrial establishments, wherein evaluation of the impact of residential and industrial activities on water resources could be performed. Considerable efforts were made to evaluate major ion chemistry along with estimation of heavy metal contamination, which could serve as a basis for planning health risk assessment studies in the future. The research design employed a holistic approach, including assessment of water quality using various water quality and pollution indices like groundwater quality index (GWQI), the heavy metal pollution index (HPI), heavy metal evaluation index (HEI) and degree of contamination (C_d), followed by principal component analysis (PCA) and cluster analysis (CA). By integrating the tools mentioned above with geospatial analysis, the study identified the possible sources and hotspots of contamination along with the dominant factors affecting groundwater quality. The intention of characterising hydrochemistry within this region will be crucial step in achieving SDG6, reducing contamination and ensuring the long-term availability of pure groundwater.

In light of the factors mentioned above, this the research was designed in an industrialized district (Gurugram) of Haryana with the following objectives: (1) Assessment of the status of heavy metal contamination in groundwater resources (2) Assessment of water potability using various water quality and pollution indices (3) Identification of pollution sources and dominating factors using multivariate analysis (4) Determination of the spatial distribution of various pollutants using geospatial technology.

Materials and methods

Study area

Gurugram, positioned at 28^{o}27′34.19″ North latitude and 77^{o}1′35.88″ Eastern longitude, covers a total geographical area of 1,258 km^2 with a mean height of 217 m above sea level. The climate in the district is semi-arid, with arid weather except during the monsoon season. Major portion of the district comprises old alluvial plains and Quartzite ridges resulting in a highly irregular topography (Rajput and Shekhar 2015). As a result, the study area has been subjected to uneven rainfall patterns and restricted groundwater availability. The combined effect of these natural and anthropogenic factors has placed considerable strain on groundwater resources. Due to this, the district has been classified as a dark zone (an area where groundwater depletion exceeds groundwater replenishment) (Malik and Rajeshwari 2015).

Gurugram was identified as a potentially vulnerable area, in terms of groundwater degradation through literature reviews, media articles, and scientific reports published by the Central Ground Water Board (2017) due to deteriorating water quality caused by overuse, modernization, and industrialization. Specifically, Industrial Model Township (IMT) Manesar, which is a hub of around 2000 industries (including automotive and other units) in the Gurugram district, was selected to evaluate the impact of ongoing industrial and residential activities on the local groundwater resources. A reconnaissance survey was conducted to assess groundwater quality status and recognize the probable source of contamination, along with groundwater sample collection. Results of the on-site survey and preliminary analysis were used to demarcate sampling areas. Figure 1 illustrates the location of the study area and sampling sites.

Furthermore, the sampling areas were deliberately selected within a five-kilometre radius of the Industrial Model Township to determine contamination levels due to effluent discharge. Several large industrial units and a wastewater treatment plant were close to Khoh, Naharpur Kasan, Bhangrola, Kankrola, Bas Kushla, Bas Haria, and Dhana. Thus, these seven villages were chosen for further study and assessment.

Sampling and analysis

To determine the appropriateness of groundwater quality for human consumption and its spatial variability, a total of 21 sampling sites, three from each village, were selected to eliminate human error in the collection and analysis processes. The study was conducted during the post-monsoon season to investigate how runoff affects underground water quality. Samples were collected from 2019 to 2021 during the months of October–November. The present study used data from 2021 to represent the most recent status of groundwater quality since similar trends were observed in previous years. High-density polyethylene (HDPE) bottles were used for sample collection. In order to avoid contamination, water was allowed to flow for ten minutes, followed by washing of sampling bottles thrice with sample water before collection. Samples for heavy metal detection were acidified using 5 ml of nitric acid for sample preservation and stabilization of heavy metals.

Water samples were analyzed in-situ for pH, dissolved solids (TDS) and electrical conductivity (EC) with an Oakton® multi-parameter PCST tester. Moreover, total alkalinity (TA), hardness, calcium, magnesium, bicarbonate, fluoride and nitrate were evaluated using the standard procedures

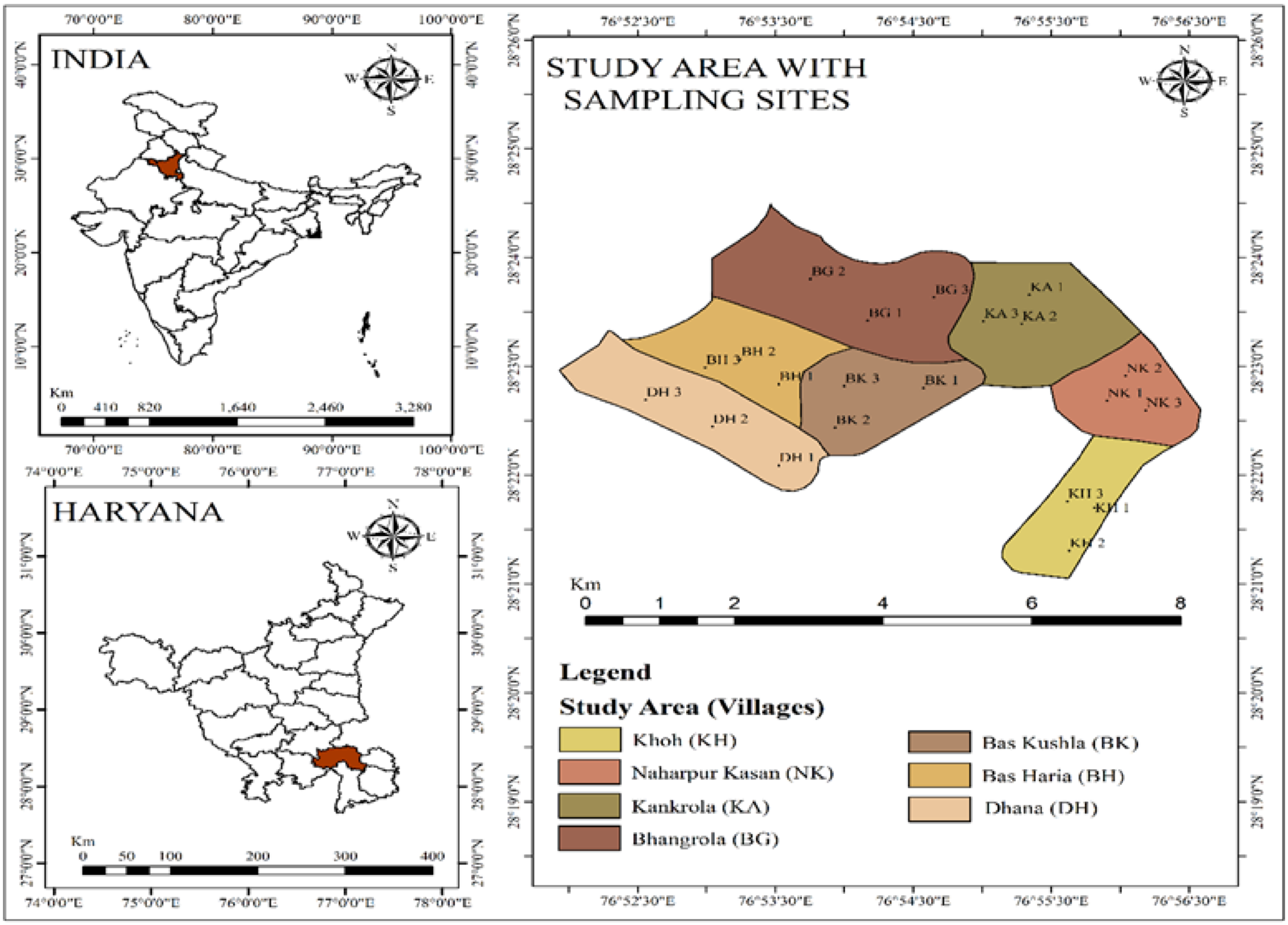


Fig. 1 Location map of the study area

prescribed by the American Public Health Association (2005). Atomic Absorption Spectrophotometer (Agilent Technologies 200 series AA), calibrated linearly with custom standards, was used to detect the concentration of cadmium, chromium, nickel and lead in the samples. Finally, to determine whether the water was potable, the findings were compared with standards set forth by the Bureau of Indian Standards (BIS) (IS 10500: 2012). A diagram of the brief methodology adopted for this study is presented in Fig. 2.

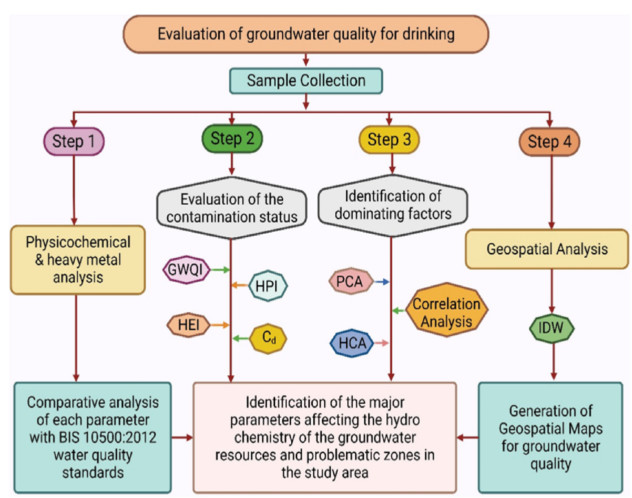


Fig. 2 Descriptive diagram of the methodology

Water quality evaluation indices

Water evaluation indices assist in determining overall water quality by providing a single value based on various parameters at a particular location and time (Adelagun et al. 2021). Four indices used to determine the contamination status of groundwater resources in the study area were (a) groundwater quality index (GWQI) (b) heavy metal pollution index (HPI) (c) heavy metal evaluation index (HEI) (d) degree of contamination (C_d). While GWQI only indicated the overall ground water quality, other three indices were taken to understand the quality status of water in term of heavy metals contamination. Amongst these three specific indices, HPI & C_d were explicit in terms of drinking water quality while HEI categorized water for general use. A brief description of the water quality and pollution indices utilized in the study is presented in this section.

Groundwater quality index (GWQI)

The National Sanitation Foundation of the United States initially established the water quality index as a standard for water quality evaluation and a method for grading water quality (Hoaghia et al. 2021). However, Ribeiro et al. (2002) first defined the GWQI as a standard groundwater quality evaluation index which is adequate for establishing the appropriateness of water for human consumption. It can be used to evaluate the contamination status of groundwater resources as it reflects the combined influence of different water quality parameters in a single value that expresses the overall water quality for drinking (Chaurasia et al. 2018). GWQI has been widely used by scholars in environmental science using Eq. (1) (Vasanthavigar et al. 2010).

$$\mathrm{GWQI} = \sum \mathrm{SI_i} \tag{1}$$

where $\mathrm{SI_i}$ in Eq. (1) is the sub-index value of the i.th parameters and is calculated through Eq. (2)

$$\sum \mathrm{SI_i} = \sum (\mathrm{W_i} \times \mathrm{q_i}) \tag{2}$$

where,

$\mathrm{W_i}$ is the relative weight of each parameter that can be calculated using Eq. (3)

$\mathrm{q_i}$ is the water quality rating calculated through Eq. (4)

$$\mathrm{W_i} = \left(\frac{\mathrm{w_i}}{\sum_{n}^{i=1} \mathrm{w_i}} \right) \tag{3}$$

In Eq. (3), $\mathrm{w_i}$ is the assigned weight according to its relative significance in determining water potability.

$$\mathrm{q_i} = \left(\frac{\mathrm{C_i}}{\mathrm{s_i}} \right) \times 100 \tag{4}$$

$\mathrm{C_i}$ in Eq. (4) is the concentration of the $\mathrm{i^{th}}$ parameter analyzed, and $\mathrm{S_i}$ is the maximum permissible limit prescribed by the Bureau of Indian Standards (BIS) (IS 10500: 2012).

Heavy metal pollution index (HPI)

The HPI measures the accumulated impact of all heavy metals on groundwater quality for drinking. It mainly depends on the number of heavy metals present in samples and their concentration regarding their maximum permissible limit in drinking water (Rezaei et al. 2019). The first step in the calculation of HPI is to assign a weightage ($\mathrm{W_i}$) to each heavy metal that is inversely proportional to its maximum permissible value ($\mathrm{S_i}$) (Kumar et al. 2020). It usually has a value between 0 and 1. This study used BIS (2012) standards as $\mathrm{S_i}$ and desirable value ($\mathrm{I_i}$) for heavy metals. HPI is calculated using Eq. (5) (Mohan et al. 1996).

$$\mathrm{HPI} = \frac{\sum_{i=1}^{n} \mathrm{W_i} \times \mathrm{Q_i}}{\sum_{i=1}^{n} \mathrm{W_i}} \tag{5}$$

where $\mathrm{Q_i}$ in Eq. (5) is the Sub-index that can be computed through Eq. (6)

$$\mathrm{Q_i} = \sum_{i=1}^{n} \frac{\{\mathrm{M_i}(-)\mathrm{I_i}\}}{\mathrm{S_i} - \mathrm{I_i}} \times 100 \tag{6}$$

where $\mathrm{M_i}$ represents the measured metal concentration in the water sample, $\mathrm{I_i}$ is the ideal value, and $\mathrm{S_i}$ is the maximum permissible limit. The negative sign (−) represents a numerical difference between two values, ignoring the algebraic sign.

The unit weight ($\mathrm{W_i}$) in Eq. (5) for each parameter is calculated using Eq. (7)

$$\mathrm{W_i} = 1/\mathrm{S_i} \tag{7}$$

The critical value (CV) for determining the appropriateness of water for drinking is 100 (Prasad and Bose 2001).

Heavy metal evaluation index (HEI)

The heavy metal evaluation index is a tool for determining the pollution level in water resources. It helps monitor overall water quality due to heavy metal contamination (Prasanna et al. 2012). Equation (8) can be used to calculate HEI (Edet and Offiong 2002).

$$\mathrm{HEI} = \sum_{i=1}^{n} \mathrm{M_i}/\mathrm{S_i} \tag{8}$$

$\mathrm{M_i}$ denotes the monitored value of the $_i{}^{th}$ heavy metal, and $\mathrm{S_i}$ denotes the maximum allowable concentration. According to Selvam and Venkatramanan (2015), HEI value of less than 10 is considered low, 10–20 is considered medium, and more than 20 is considered high.

Degree of contamination (C_d)

The degree of contamination is a quantitative tool for assessing contamination in water by combining various water quality parameters considered hazardous to household water supplies (Rahman et al. 2020). $\mathrm{C_d}$ calculation is made for each water sample separately, based on the sum of the individual parameters considered harmful for domestic use and exceeding the maximum permissible limit.

C_d can be calculated using Eq. (9) proposed by (Hakanson 1980),

$$C_d = \sum_{i=1}^{n} C_{fi} \quad (9)$$

where C_{fi} is the contamination factor for any heavy metal that can be calculated through Eq. (10)

$$C_{fi} = \left(\frac{M_i}{S_i}\right) - 1 \quad (10)$$

where M_i is the monitored value, and S_i is the maximum permissible value.

The degree of contamination can be classified as low if the value of C_d is below 1, medium if the value of C_d lies between 1–3 and high if its value is greater than 3 (Kumar et al. 2020).

Statistical analysis

To determine the source of contaminants, multivariate statistical techniques such as correlation analysis, principal component analysis (PCA), and cluster analysis (CA) are commonly used in studies related to environmental science (Bodrud-Doza et al. 2016). Multivariate analysis was done using XLSTAT (Lumivero 2023) program in Microsoft Excel. The correlation coefficient matrix assesses how each constituent's variability can be explained by its relationships with others. Cluster analysis was used to detect the spatial similarity between the grouping locations (Dhamodharan et al. 2016). The agglomerative hierarchical clustering technique was used to generate a dendrogram, commonly used to present a pictorial precis of cluster analysis (Tomar et al. 2015; Gulgundi and Shetty 2018). The current study represented distinct clusters using a dendrogram based on Euclidean distance.

PCA is commonly used to decrease data by extracting some latent factors to analyse the association between variables (Bodrud-Doza et al. 2016). Herein, PCA was used to extract principal components (PC) from the analyzed data to identify probable sources and status of groundwater contamination.

Geospatial analysis

The spatial distribution maps of water quality indices were generated using inverse distance weighted (IDW) interpolation with the help of a spatial analyst tool in ArcGIS software version 10.8. It is the most widely used method of interpolation that combines several sample points into a linearly weighted combination to determine the value of a cell. IDW interpolation determines the weight based on the distance between the measured and unknown points. Then, the expected value at each point is generated based on the weighted mean of the nearest sample point.

Results and discussion

Overview of groundwater quality characteristics

The current pollution status in groundwater resources of seven villages near IMT, Manesar, Gurugram was evaluated by analysing several parameters. According to the study, most samples exhibited high concentration of dissolved solids, hardness, fluoride, calcium, magnesium, lead, and nickel (as compared to prescribed standards); however, the content of nitrate, cadmium and chromium in all of the samples was within the acceptable limits prescribed by BIS (IS 10500: 2012) for drinking water. Since one or more parameters exceeded the standard permissible limit, it could be concluded that the area's water was unsuitable for human intake without a prior treatment. The statistical digest of the parameters analyzed is presented in Table 1.

The pH values of all 21 samples ranged from 6.81 to 7.9, with a mean value of 7.27; indicating that the samples were slightly acidic to alkaline in nature. Total dissolved solids in water samples vary significantly from 621 to 1830 mg/l, with an average value of 961.62 mg/l. All tested samples exceeded the acceptable limit of 500 mg/l for TDS in drinking water. The high concentration of TDS in the samples makes the water unfit for drinking and could cause gastrointestinal discomfort/disorders (Singh et al. 2024). High TDS have been reported earlier in, Panipat district. by Dubey et al. (2010), in Faridabad district by Kumari et al. (2018). The electrical conductivity in the water samples varied from 929 to 2542 µs/cm with a mean value of 1378.82 µs/cm. Similarly, high EC was reported in the water samples from Jind by Singh et al. (2012), in water samples from Panipat by Dubey et al. (2010), and by Ravindra and Garg (2007) in Hisar district of Haryana. Higher EC in water may be due to geogenic factors or the percolation of salts and minerals through industrial or domestic effluents/disposals.

Total alkalinity in groundwater ranged from 336 to 568 mg/l with an average value of 436.76 mg/l. Alkalinity in groundwater may be present due to the geogenic factors like rock-water interaction and anthropogenic factors like mixing of detergents present in domestic wastewater and effluents from sewage treatment plants (Ravish et al. 2020). The hardness value, which is a major indicator of potability, varied from 100 to 948 mg/l with an average of 378.33 mg/l. Among all the samples, 90.47% exceeded the acceptable limit of 200 mg/l, while 9.52% surpassed the maximum

Table 1 Statistical summary of the parameters analyzed

Variable	Minimum	Maximum	Mean	Std. deviation	Acceptable limit (AL)	Permissible limit (PL)	No. of samples beyond AL	No. of samples beyond PL
pH	6.81	7.9	7.27	0.31	6.5–8.5	6.5–8.5	0	0
TDS	621	1830	961.62	332.43	500	2000	21	0
EC (µs/cm)	929	2542	1378.82	450.68	–	–	–	–
Total Alkalinity	336	568	436.76	69.77	200	600	21	0
Hardness	100	948	378.33	188.57	200	600	19	2
Calcium	11.77	198.49	69.79	43.11	75	200	7	0
Magnesium	17.16	156.00	53.45	29.97	30	100	19	1
Bicarbonates	156	478.13	319.79	93.88	–	–	–	
Fluoride	0.032	2.47	0.93	0.60	1	1.5	9	3
Nitrate	5.31	15.10	12.78	2.86	45	45	0	0
Cadmium	0	0.003	0.001	0.001	0.003	0.003	0	0
Chromium	0.004	0.022	0.015	0.004	0.05	0.05	0	0
Nickel	0.006	0.150	0.073	0.042	0.02	0.02	20	20
Lead	0	0.120	0.035	0.029	0.01	0.01	16	16

*All the parameters are measured in mg/l except for pH and EC

permissible limit of 600 mg/l (BIS, IS-10500:2012). The excess concentration of divalent cations could be primarily accountable for hardness in water. Intake of hardwater for long duration may cause severe health risks like renal failure and cardiovascular disorders (Chabukdhara et al. 2017; Sharmin et al. 2020).

Individual cationic and anionic details for the research area are presented herewith. Calcium and magnesium significantly contributed to hardness of groundwater ranging from 11.77 to 198.49 mg/l and 17.16 to 156 mg/l, respectively. The calcium concentration exceeded the acceptable limit of 75 mg/l in 33.33% of the samples. Excess concentration of calcium in water could be attributed to the presence of underlying quaternary alluvium rocks comprising of sand, silt and clay. Long-term water consumption with high calcium concentrations may result in kidney stones, urinary tract infections, cardiovascular disease, osmoregulation issues, reproductive failure, and growth retardation (Masood et al. 2022). Interestingly, a similar range of calcium in water samples was reported by Ravindra and Garg (2007) from Hissar district, Haryana.

Magnesium concentration surpassed the maximum limit of 100 mg/l in 4.76% of the samples. Intake water laden with high magnesium cause gastric disorders and diarrhoea. In addition, the results of magnesium concentration were consistent with the findings of a study conducted by Bharti et al. (2013) on groundwater samples from the Panipat district, Haryana. The concentration of bicarbonates in the samples varied from 156 to 478.13 mg/l. The excess concentration of ions in groundwater could be attributed to the dissolution of carbonate minerals from the surrounding soils and rocks.

Fluoride is a double-edged sword as it is required in small amounts for proper body functioning, but its excess may be detrimental to human health. There were significant concerns with respect to fluoride in the area, as its concentration ranged from 0.032 to 2.47 mg/l. Among the water samples, 42.86% exceeded the acceptable limit of 1.0 mg/l, whereas 14.29% samples surpassed the permissible limit of 1.5 mg/l. The reason for elevated concentration of fluoride in water could be the geogenic factors like fluoride bearing underground rocks as well as anthropogenic factors, viz excessive use of agrochemicals and coal burning (Shaji et al. 2024). A similar study in different districts of Haryana by Ravish et al. (2019) reported similar fluoride levels in Yamunanagar and Ambala districts. However, the mean fluoride concentration in the study area was much lower than the concentration reported by Ambastha and Haritash (2021) in Mahendragarh district, Haryana.

It is incredibly critical to determine the level of nitrates in water because high levels of nitrates can cause blue-baby syndrome (Methamoglobinemia). In this regard, the nitrate concentration in the samples was determined and was found to be within the acceptable limit of 45 mg/l. In water samples, calculated nitrate content was found to lie between 5.31 to 15.10 mg/l. The average nitrate level in the study region was lower than that reported in the Faridabad district by Kumari et al. (2018) but higher than those reported by Ravish et al. (2019) from Yamunanagar and Ambala. Similar range of nitrate was reported by Ambastha and Haritash (2021) in water from Mahendragarh district.

Evaluating the extent of metal contamination in groundwater is critical because it can be harmful to human health, even in trace amounts. For this purpose, the concentrations of four ubiquitous toxic heavy metals in (Cd, Cr, Ni, and Pb) in groundwater were chosen for the study. The mean concentration of these metals in the water exhibited the following trend Ni > Pb > Cr > Cd. Chromium was considered an essential water quality parameter to be analyzed because of its toxic and carcinogenic health effects. Cr concentration in water ranged from 0.004 to 0.022 mg/l, with all samples falling within the permissible limit of 0.05 mg/l. Similar, concentration of Cr was reported by Rosin et al. (2013) in Faridabad district. Assessment of nickel in water is also crucial as its ingestion may cause "Nickel itch", a severe skin disease (ATSDR 2005). Nickel concentration in the water samples ranged from 0.006 to 0.150 mg/l, which was slightly higher than the permissible limit of 0.02 mg/l in few samples. Similar value for nickel was reported by Dubey et al. (2010) in Panipat district. Additionally, monitoring cadmium contamination in water is also important, as its excessive consumption may cause "Itai-Itai" disease. Its concentration in water samples varied from 0.00 to 0.003 mg/l, which was within the maximum permissible limit. Cadmium levels in the samples was lower than the concentration reported by Dubey et al. (2010) in Panipat, Haryana. Lead, a neurotoxic and carcinogenic metal, ranged from 0.00 to 0.12 mg/l in the analyzed water samples. There is an urgent need to monitor the water resources in the area because 76.19% of the samples exceeded the permissible limit of 0.01 mg/l of Pb in drinking water. It was found that the lead concentration in groundwater samples was lower than that reported by Rosin et al. (2013) in the Faridabad district and by Dubey et al. (2010) in Panipat district, Haryana. The comparative assessment of the parameters analyzed in the present study with other similar studies carried out in different districts of Haryana is presented in Table 2.

Groundwater quality index (GWQI)

GWQI was used to assess the appropriateness of groundwater quality for human intake; based on the level of contamination with emphasis on the most common parameters associated with water quality. It simplifies complex data about water quality into a type of information that the general public can comprehend and use to make decisions about water consumption. The GWQI values for the study area varied from 83.92 to 172.92, with a mean value of 115.25. Analysis of the GWQI values for this study exhibited that 47.62% of the samples (NK1-2, KA1-3, BG1-2, BK2-3, and BH1) had a good water quality, whereas 52.38% of the samples (KH1-3, NK3, BG3, BK1, BH2-3, and DH1-3) had poor water quality. The result of GWQI analysis was supported by Yadav et al. (2023) who reported that water was unfit for drinking in Gurugram. Moreover, through GWQI it was concluded that samples from site-2 of Dhana village were

Table 2 Comparison of parameters analyzed in the present study area with similar studies carried out in the other districts of Haryana

Sites	TDS	EC	Alkalinity	Hardness	Calcium	Magnesium	Fluoride	Bicarbonate	Chromium	Nickel	Cadmium	Lead	Reference
Gurugram	621–1830	929–2542	336–568	100–948	11.7–198.49	17.16–156	0.03–2.47	156–478	0.004–0.022	0.006–.150	0.00—.003	0.00–0.12	Present Study
Panipat	650–1510	1330–3900	–	–	–	–	–	237.9–567.3	–	0.00–0.13	0.00–0.29	0.11–0.42	(Dubey et al. 2010)
Jind	422–8659	660–13530	118–4615	108–1536	11–200	–	6.9–30	143–1068	–	–	–	–	(Meenakshi et al. 2004)
Jind	1018–5165	1100–5700	305–995	274–964	7.00–109	8.1–96	0.47–2.72	7–142.8	–	–	–	–	(Singh et al. 2012)
Jhajjar	74.4–3920	103.5–5640	–	100–2740	–	–	0.3–9.3	–	–	–	–	–	(Gupta and Misra 2018)
Panipat	260–2160	–	–	–	13–157	–	0.5–5.95	195–940	–	–	–	–	(Kaur and Rishi 2018)
Hisar	102–1860	690–880	–	–	–	–	0.5–2.98	–	–	–	–	–	(Kumar and Sharma 2017)
Gurugram	60–3731	–	102–582	50.47–2984	9–481	6.8–2922	0.02–6.4	–	–	–	–	–	(Manjeet and Sharma 2014)
Hisar	597–3242	900–5100	309.7–756	382–1702	27.7–378	44.7	0.1–4.0	348.3–889	–	–	–	–	(Ravindra and Garg 2007)
Faridabad	–	–	–	–	–	–	0.23–1.84	–	0.00–0.03	0.1	–	0.07–0.69	(Rosin et al. 2013)
Sonipat	192–6570	384–13,140	–	15.39–282.42	–	1.48–200.6	0.58–6.75	166.4–558.7	–	–	–	–	(Sheikh et al. 2017)

severely contaminated and unsuitable for drinking without treatment, while samples from Kankrola village (site-3) were the least contaminated.

Heavy metal pollution index (HPI)

HPI is used to appraise the impact of heavy metals on the suitability of water for drinking. The assessed values of cadmium, chromium, nickel, and lead were taken into account to calculate the value of HPI, using BIS standards (IS 10500:2012). The computed value of HPI varied from 61.13 to 307.79, with a mean value of 131.63. The HPI value for the study area exhibited that 33.33% of the samples (KA2-3, BG2, BK2-3, BH1, DH3) showed a medium pollution level as they fell below the critical value of 100. On the other hand, 66.67% of the samples exhibited a high level of pollution (KH1-3, NK1-3, KA1, BG1 and BG3, BK1, BH2 and BH3, DH1 and DH2). The groundwater resources at Khoh village sampling site 1 were severely polluted with heavy metals. In contrast, Bans Haria village sampling site 1 showed least contamination.

Heavy metal evaluation index (HEI)

HEI is a clear indicator of the aptness of water for various purposes other than drinking. The evaluated values of cadmium, chromium, nickel, and lead were taken into account to calculate the value HEI, using BIS standards (IS 10500: 2012). There was a wide range of HEI values between 4.15 and 13.47, with a mean of 7.84. The HEI values indicated a low to medium level of pollution in the study area, indicating that water was usable for industrial, agricultural and household purposes other than drinking. Maximum and minimum values of HEI were reported from Dhana village site-2 and Bhangrola village site-2 respectively. Results of water evaluation indices with their critical value are summed up in Table 3.

Table 3 Calculated value of the water quality evaluation indices for each sampling site

Sampling Sites	GWQI	HPI	HEI	C_d
KH 1	171.5	307.76	13.37	11.0
KH 2	128	158.13	8.17	6.89
KH 3	117.1	164.11	8.01	4.3
NK 1	96.52	118.37	6.24	3.55
NK 2	94.77	122.92	6.71	4.0
NK 3	127.2	175.79	8.15	5.74
KA 1	97.74	106.53	6.06	3.35
KA 2	86.25	75.44	4.81	2.66
KA 3	83.92	71.46	5.41	3.05
BG 1	95.84	141.25	6.78	3.4
BG 2	84.85	68.05	4.15	1.5
BG 3	133.63	115.51	9.82	7.5
BK 1	100.77	104.65	6.81	4.2
BK 2	93.42	65.11	5.71	3.45
BK 3	97	63.92	4.71	3.1
BH 1	95.73	61.13	6.31	5.05
BH 2	161.28	197.31	13.03	10.75
BH 3	125.31	191.51	9.78	6.5
DH 1	149.96	168.41	9.49	6.15
DH 2	172.92	202.03	13.47	11.25
DH 3	106.51	84.89	7.69	5.45
Maximum	172.92	307.79	13.47	11.25
Minimum	83.92	61.13	4.15	1.5
Mean	115.25	131.63	7.84	5.38
CV*	>100	100	NA	>3
Percentage of Samples exceeding CV	52.38%	66.67%	NA	90.48%

*Value used to determine the appropriateness of water for drinking

Degree of contamination (C_d)

Compared to HPI and HEI, the C_d provides a more comprehensive picture of the extent of heavy metal contamination in water as well as its acceptability for human consumption. Since the computation of C_d is solely based on parameters that are considered hazardous and exceed the maximum permissible limit. An evaluation of the contamination level in the aquifer resources of the study region was based on four health-risk-based indicators, including fluoride, cadmium, nickel, and lead. Moreover, elemental species like nitrate and chromium with analytical values within the maximum permissible limit were excluded from the computation of C_d. The C_d value for the samples ranged from 1.5 to 11.25. According to the study, approximately 9.52% of samples (KA2, BG2) showed a medium level of contamination, while approximately 90.48% of samples (KH1-3, NK1-3, KA1 and KA3, BG1 and BG3, BK1-3, BH1-3, DH1-3) exceeded the critical value of 3, indicating high levels of contamination. It was found that consumption of water without prior treatment might pose several health risks to residents of DH2, while the risk was least for residents of BG2. Categories of water quality based on the water evaluation indices are exhibited in Table 4.

Evaluation of water quality through correlation matrix

Correlation analysis was performed to determine the degree of relationship between the two variables, as it is used to measure and establish the relationship between variables and further characterize and distinguish the significant hydrogeochemistry of aquifers (Tashtoush and Al-Subh 2015). Keeping in view of the same, correlation analysis

Table 4 Classification of groundwater quality within the study area based on water quality and pollution indices

Indices	Range	Status of water quality	Number of sampling sites	Per cent of samples	Sampling sites
GWQI	< 50	Excellent water	0	0%	NIL
	50–100	Good water	10	47.62%	NK1, NK2, KA1, KA2, KA3, BG1, BG2, BK2, BK3, BH1
	100.1–200	Poor water	11	52.38%	KH1, KH2, KH3, NK3, BG3, BK1, BH2, BH3, DH1, DH2, DH3
	200.1–300	Very Poor water	0	0%	NIL
	> 300	Unfit for Drinking	0	0%	NIL
HPI	< 45	Low Pollution	0	0%	NIL
	45–90	Medium Pollution	7	33.33%	KA2, KA3, BG2, BK2, BK3, BH1, DH3
	> 90	High Pollution	14	66.67%	KH1, KH2, KH3, NK1, NK2, NK3, KA1, BG1, BG3, BK1, BH2, BH3, DH1, DH2
HEI	< 10	Low Pollution	18	85.71%	KH2, KH3, NK1, NK2, NK3, KA1, KA2, KA3, BG1, BG2, BG3, BK1, BK2, BK3, BH1, BH3, DH1, DH3
	10–20	Medium Pollution	3	14.29%	KH1, BH2, DH2
	> 20	High Pollution	0	0%	NIL
C_d	< 1	Low Pollution	0	0%	NIL
	1–3	Medium Pollution	2	9.52%	KA2, BG2
	> 3	High Pollution	19	90.48%	KH1, KH2, KH3, NK1, NK2, NK3, KA1, KA3, BG1, BG3, BK1, BK2, BK3, BH1, BH2, BH3, DH1, DH2, DH3

was incorporated into the study to determine the factors that could be used to quantify the crucial parameters for evaluating water quality. Strong correlations between TDS, hardness, calcium, magnesium and EC indicated that the high concentration of dissolved solids was responsible for high conductivity and hardness. Total hardness correlated strongly with calcium and magnesium suggesting that these ions dominated the hydrochemistry, contributed significantly to hardness; and originated from a similar source. A positive correlation between nitrates and calcium was also found. This indicates that geogenic processes, such as weathering of underground rocks, significantly contributed to groundwater contamination with nitrates and calcium. There was no significant correlation between metals and other water quality parameters. This indicated that physicochemical parameters were not the main factors affecting the mobility of toxic metals in the groundwater (Ukah et al. 2019). Moreover, insignificant correlation among the metals indicated their different source of origin. The correlation matrix for the parameters analyzed is depicted in Table 5.

Correlation analysis for water evaluation indices

Significant correlations among all the water evaluation indices depict that all these four indices can be used to evaluate the overall heavy metal contamination risk in the region. The correlation analysis determined that lead was the primary factor contributing to each of the indices because, it showed a strong correlation with them, followed by cadmium, which was moderately correlated with HPI only. It can be concluded that lead and cadmium contributed significantly to heavy metal contamination, posing severe health risks to local residents. An overview of the findings of correlation analysis for different water quality indices can be seen in Table 6.

Agglomerative hierarchical clustering

By analysing the hydrochemical characteristics of the groundwater quality, sampling locations in the study area were classified into three major clusters. The first cluster comprised twelve sites (KH1-3, NK1-3, KA1-3, BG1 and BG2, BK1), whose water quality was greatly affected by anthropogenic activities. Due to the influence of alkalinity, TDS, calcium, magnesium, fluoride, lead and nickel on water quality, these sites were found to be moderately to highly polluted. Figure 3 illustrates the findings of cluster analysis in the form of a dendrogram and profile plot.

Cluster two consisted of seven sampling stations (BG3, BK2, BH1-3, DH2 and DH3). Water quality in this cluster was predominantly influenced by geological and anthropogenic sources, as evidenced by the high levels of calcium, magnesium, lead and nickel. It is noteworthy that cluster three consisted of the two most contaminated sites in the study area, viz., BK3 and DH1. The water quality in this cluster was severely affected by high TDS, alkalinity, hardness, magnesium, bicarbonates, fluoride, nitrate and nickel levels.

Table 5 Pearson correlation matrix of the parameters analyzed

Variables	pH	TDS	EC	Alkalinity	Bicarbonate	Hardness	Calcium	Magnesium	Fluoride	Nitrate	Cadmium	Chromium	Nickel	Lead
pH	**1**													
TDS	**−0.46**	**1**												
EC	−0.33	**0.89**	**1**											
Alkalinity	−0.16	0.37	0.25	**1**										
Bicarbonate	**−0.53**	0.41	0.19	0.14	**1**									
Hardness	**−0.57**	**0.62**	**0.61**	−0.24	0.31	**1**								
Calcium	**−0.52**	**0.54**	**0.55**	−0.34	0.21	**0.89**	**1**							
Magnesium	**−0.44**	**0.65**	**0.65**	−0.01	0.28	**0.82**	**0.64**	**1**						
Fluoride	0.12	0.07	0.04	0.14	−0.03	−0.07	−0.22	0.17	**1**					
Nitrate	**−0.72**	0.29	0.22	0.05	0.29	**0.54**	**0.55**	0.37	−0.008	**1**				
Cadmium	0.24	0.26	0.29	−0.22	−0.13	0.23	0.36	0.34	−0.02	−0.02	**1**			
Chromium	−0.02	0.11	0.07	0.39	0.02	−0.23	−0.21	0.003	0.04	−0.22	0.04	**1**		
Nickel	**−0.54**	0.10	0.07	−0.05	0.32	0.29	0.22	0.13	**−0.59**	0.16	−0.35	−0.17	**1**	
Lead	0.38	−0.31	−0.18	**−0.50**	−0.22	−0.07	0.09	−0.18	0.31	0.08	0.32	−0.40	−0.42	**1**

Table 6 Correlation matrix for the values of pollution indices and heavy metal concentration

Variables	GWQI	HPI	HEI	C_d
GWQI	**1**			
HPI	**0.857**	**1**		
HEI	**0.964**	**0.864**	**1**	
C_d	**0.950**	**0.795**	**0.973**	**1**
Cadmium	0.255	**0.579**	0.207	0.067
Chromium	**− 0.512**	− 0.407	**− 0.514**	**− 0.625**
Nickel	0.232	− 0.194	0.265	0.290
Lead	**0.738**	**0.906**	**0.755**	**0.733**

*Values in bold are different from 0 with a significance level of alpha = 0.05

Identification of sources and factors governing the groundwater quality

Principal component analysis (PCA) was used to identify critical factors affecting water quality (Li et al. 2020). The Eigenvalue denotes the importance of the varifactor with Eigenvalues greater than unity being considered as significant (Rizvi et al. 2015). The Scree plot was employed in this investigation to conclude that the first four factors with Eigenvalues above one were significant. Consequently, the first four principal components (PCs) for the water quality parameters, accounting for 76.88 per cent of the overall variability, were chosen for the study.

Principle component 1 exhibited 34.54% of the total variability. It was strongly loaded by dissolved solids, total hardness, calcium, and magnesium and moderately by EC and nitrate. These parameters were also strongly correlated, representing their common source of origin. According to PC 1, high concentrations of calcium and magnesium in the water samples were primarily responsible for the high dissolved solids and hardness. This suggests that water quality might be affected by various natural processes, including soil quality, water infiltration frequency, and agricultural runoff. PC 2 displayed 17.74% of the total variability and was strongly loaded with lead and moderately loaded with cadmium, possibly due to the chemical leaching from industrial, agricultural, and household waste sources. Therefore, it could be concluded that PC 2 for the water quality is predominantly influenced by human-induced activities. A matrix illustrating the significant principal components is shown in Table 7.

On the other hand, PC 3 demonstrated 15.01% of the total variability and was moderately loaded with nickel, concluding that human-induced sources duly dominated the area. Moreover, PC4 exhibited 9.59% of the total variability and was moderately loaded with fluoride, which might be attributed to anthropogenic and geogenic processes, such as the dissolution of fluoride-bearing rocks. To provide an

Fig. 3 Results of Cluster analysis of groundwater samples (**a**) Dendrogram (**b**) Profile plot

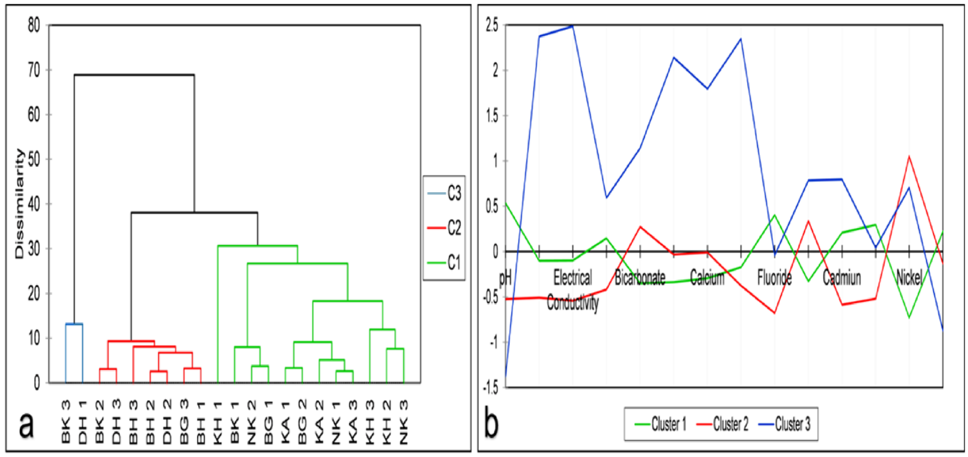


Table 7 Principal components matrix

Parameters	PC1	PC2	PC3	PC4
pH	−0.759	0.369	−0.259	−0.305
TDS	**0.808**	−0.081	−0.458	−0.078
EC	**0.746**	0.067	−0.444	−0.185
Total Alkalinity	0.060	−0.644	−0.562	0.175
Bicarbonate	0.498	−0.334	0.092	0.279
Hardness	**0.900**	0.276	0.130	−0.037
Calcium	**0.822**	0.395	0.196	−0.144
Magnesium	**0.812**	0.196	−0.239	−0.028
Fluoride	−0.115	0.264	−0.546	**0.677**
Nitrate	**0.619**	0.075	0.259	0.498
Cadmium	0.187	**0.637**	−0.336	−0.421
Chromium	−0.071	−0.427	−0.550	−0.220
Nickel	0.383	−0.484	**0.628**	−0.248
Lead	−0.262	**0.801**	0.124	0.293

*Strong and moderate loading factors for each PC are highlighted in bold font

overview, PCA, bi and bootstrap plots for PC 1 and PC 2 are depicted in Fig. 4.

Geospatial maps

Geospatial analysis of the water quality evaluation indices used in the study revealed that the western and south-eastern regions of the study area were severely affected by groundwater contamination. Furthermore, the water quality in aquifers in these areas was degraded up to the level where it cannot be used for drinking without any prior treatment. The geospatial map for GWQI exhibited that water quality in approximately 40% of the study area was poor. The severity of overall contamination was highest in Dhana village followed by Khoh village and Bas Haria villages. Whereas, the water in Kankrola village had least contamination and was suitable for drinking. The geospatial maps for heavy metal pollution indices (HPI) revealed that Khoh village followed by Dhana village were the areas that required urgent attention due to the severity of heavy metal contamination. In contrast, Bas Kushla village had the least impact of heavy metals on water potability. However, considering the geospatial maps of (HEI and C_d), Kankrola village, which had moderate levels of pollution in its aquifers, was identified as the least polluted. However, the water resources of Dhana village showed the highest level of toxic contamination which may pose significant health risks to the residents. Figure 5 illustrates spatial distribution maps for all four indices.

Findings of the study will provide critical information about the safety and suitability of groundwater in the study area for various purposes. It is anticipated that the dominant contaminants identified through physicochemical and multivariate analysis may provide background information to regulatory authorities. This will enable them to draft monitoring and regulation programs for water quality according to the specific needs of the study area. The resulting geospatial maps can serve as an effective visual tool for local agencies and communities to mitigate contamination and maintain clean and safe water resources by implementing appropriate water treatment technologies or improving waste management practices. Additionally, the study will raise community awareness about the importance of clean water and potential health risks associated with poor water quality.

Conclusion

Through this study, authors have tried to provide adequate background information on the status of groundwater quality and identify probable sources of contamination in Gurugram district, Haryana. The study suggests that water quality degradation may be attributed to the excessive concentration of dissolved solids, hardness, calcium, and magnesium. In

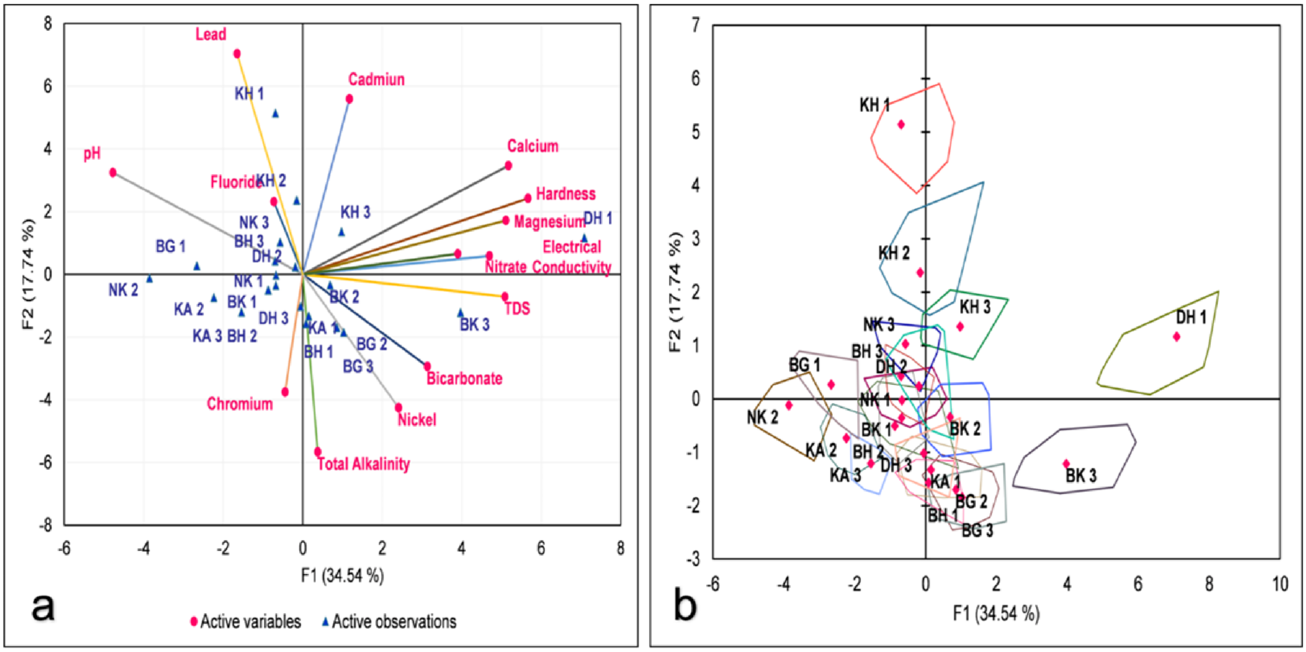


Fig. 4 PCA plots (**a**) Bi – plot (**b**) Bootstrap diagram of PC 1 and PC 2

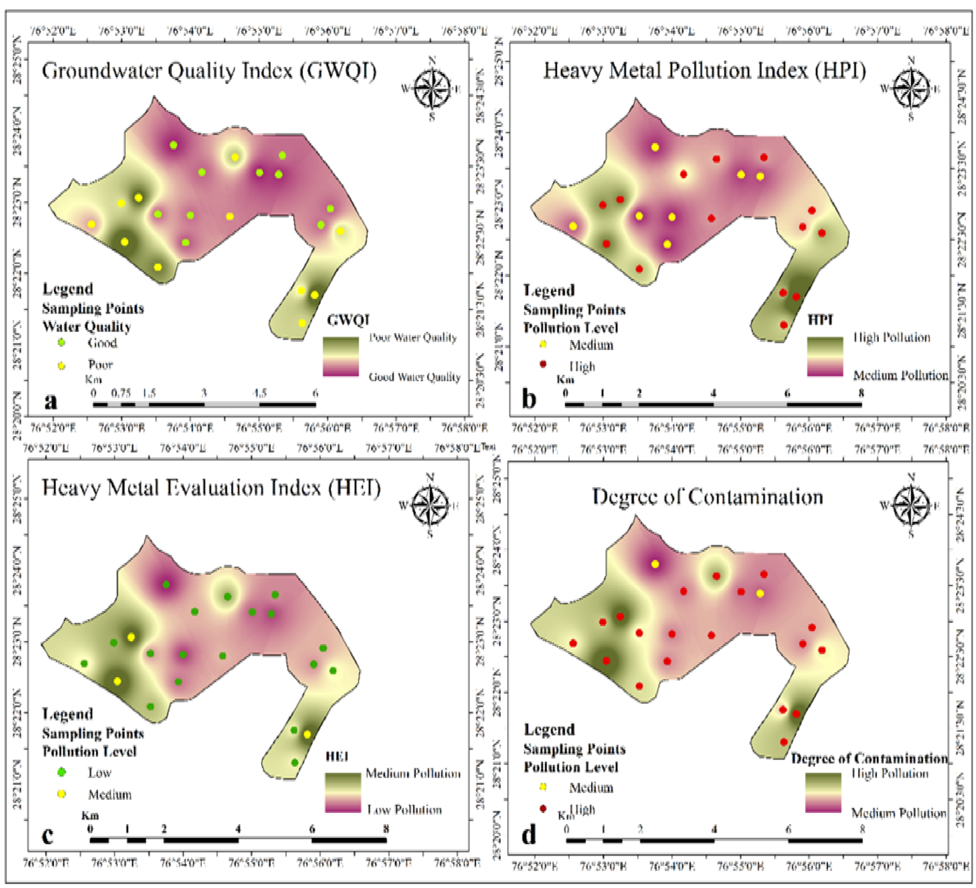


Fig. 5 Spatial distribution maps of groundwater quality based on (**a**) GWQI (**b**) HPI (**c**) HEI (**d**) C_d

addition, an elevated concentration of fluoride, lead and nickel was found to be of grave concern to residents due to their detrimental health effects. Nearly 52% (as per GWQI) and 90% (as per C_d) of the water samples exhibited poor quality and were unfit for drinking. An analysis of GWQI and C_d revealed that residents of Dhana village were most vulnerable to health risks associated with contaminated water, while those of Kankrola were least affected. HPI results demonstrated that 67% of the samples had a high level of contamination. Furthermore, HPI also revealed that heavy metal contamination was widespread in aquifers in Khoh village, but least prevalent in Bas Kushla. The water quality and pollution indices indicated that water quality in Dhana was poor, while heavy metal contamination was more severe in Khoh village.

Findings of PCA and cluster analysis indicated that the groundwater chemistry of the area might be primarily governed by geological (rock-water interaction) and anthropogenic (leaching of discharged effluents, agrochemicals, and untreated sewage) factors, and has been adversely affected by rapid industrial and residential growth. Besides that, geospatial analysis revealed that the south-eastern, western regions and certain areas located within the northeastern zone require urgent attention due to the severity of contamination in groundwater. The results of the study are truly indicative of the alarming situation developing due to heavy metal contamination in rapidly industrialising areas. The data so generated through this research could be used to study future trends in policy making for different types of land use planning and water conservation programmes.

Future recommendations

The present study indicated that the concentration of toxic contaminants in groundwater of the study area exceeded the acceptable limits. These contaminants on ingestion, can cause severe health issues like skin problems, mental retardations, gastrointestinal disorders, skeletal problems and even cancer. Moreover, the elevated concentration of these chemicals can cause irreversible harm to vulnerable groups including pregnant and lactating women, infants, children and senior citizens. Thus, monitoring and management of groundwater resources is crucial to avoid future contamination. Some area-specific and generic mitigation measures that can help to restrict further water quality degradation in the study area are discussed herewith.

- It is recommended that plants capable of removing lead and nickel from the soil, and groundwater resources, be distributed and planted by local authorities in collaboration of horticulture department in the parks and around the industries.
- Phytoremediation in the study area might be aided by the species including tuberose, Ethiopian Mustard, Castor, dahlia, calendula, rose, marigold and chrysanthemum.
- Recycling of used water should be mandated in public and official lavatories.
- Anganwadi workers of the study region should be properly trained to organize mass awareness programs for housewives regarding fluoride contamination in aquifers, symptoms of its toxicity, and possible home remediation measures to reduce its severity.
- Roof top rain water harvesting systems should be installed in government offices, schools and, colleges.
- *In-situ* treatment and recycling of waste water should be mandated to avoid discharge of untreated sewage or industrial effluents directly on to the soil.
- Domestic wastewater disposal into surface water bodies is one of the major sources of groundwater contamination in the study area. In order to restrict this practice, the local population should be educated regarding its detrimental effects on health. If the situation persists, heavy penalties should be imposed on defaulters to prevent this practice from occurring in the future.

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Authors' contribution This study was designed and implemented by all authors, where all contributed to writing the manuscript, interpreting information presented, and have read and agreed to the final version of the manuscript.

Data Availability The data used/analyzed in the paper are available in tabular form within the manuscript.

Declarations

Conflict of interest The authors declare that there is no conflict of interest.

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