Geographic information system-based groundwater quality assessment for drinking and irrigation purposes in Transboundary aquifers of River Ravi, in parts of NW India

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Research Article

Keywords: Groundwater quality, ransboundary aquifers, Entropy water quality index, Irrigation water quality index, Mineral saturation index, Agrarian

Posted Date: July 18th, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1792315/v1

Abstract

Access to safe and clean drinking water is a basic human right and assessment of groundwater suitability for drinking purpose imparts significant role in providing clean and suitable water for human consumption. The main objective of this study was to assess the groundwater quality status of Gurdaspur district falling along international boundary of Indo-Pak thus serving as transboundary aquifers, for drinking and irrigation purpose based on physicochemical analysis of 111 samples using standard numerical indexes and GIS techniques. The results of Entropy Water Quality Index revealed that the drinking groundwater quality were found to be in excellent, good and medium water class except 5 samples which were in poor to extremely poor water class. Piper trilinear plot revealed that the main water types were Ca, Mg-HCO_3^-. Mineral Saturation Index indicated that carbonate minerals were oversaturated and the evaporative minerals were undersaturated. The outcomes of principal component analysis indicated that the ion exchange, weathering and agricultural practices were the dominant controlling factors in the study area. Furthermore, the results of the Irrigation Water Quality Index illustrated that 3 and 65 samples were placed in “severe restriction” and “high restriction” class respectively indicating irrigation water as an issue for sustainable agricultural production in agrarian dominant district.

Introduction

Groundwater is foremost reservoir of water prospect which exclusively fulfils domestic, agricultural, socio-economic development and recreational requirements of water. Across the world, 65% of groundwater is utilized for drinking prospect, 20% is used for livestock and irrigation purpose and 15% is for industry and mining usage (Salehi et al. 2018; Adimalla et al. 2020). In recent scenario groundwater pollution has increased tremendously throughout the world due to growth in population and intensive agricultural practices. The quality of groundwater resources is equally important as its quantity; thus, the need of the hour is to consider the quality of groundwater resources at priority (Aghazadeh and Mogaddam 2010; Neisi et al. 2018; Abbasnia et al. 2019). Long term exposure to deteriorated water quality has resulted into increased water borne diseases, including diarrhea, dysentery, chlorosis, fluorosis and cholera (Chan and Griffiths 2010; Li et al. 2017; Li and Wu 2019; He et al. 2021). Access to clean water for drinking consumption has been recognized as human right by the United Nations. According to its report approximately 10% of the population (urban and rural) does not have access to safe and clean drinking water (United Nations 2015). As a result, they rely on unsafe and poor-quality water sources to fulfil their daily requirements. Utilization of water with poor quality usually urge prolonged ill health which is particularly the main source of premature death in many parts of countries.

Several studies have been done extensively to assess the quality of groundwater for domestic and irrigational uses in Punjab and numerous parts of the world (Mohebbi et al. 2013; Fallahati et al. 2020; Subba Rao 2020; Adimalla 2021; Zakaria et al. 2021). In recent years, Geographic information system (GIS) has appeared as an influential tool for gathering, investigating and presenting the data spatially and then utilizing this data for making decisions in numerous fields of water resources (Dhanasekarapandian et al. 2016; Magesh and Elango 2019; Kamble et al. 2020; Ram et al. 2021).

Abbasnia et al. (2018) evaluated the groundwater quality in Sistan and Baluchistan province of Iran using the WQI associated with GIS for drinking and irrigational water quality and stated that 39%, 6% and 1.7% of sampled groundwater was found to be in 'poor', 'very poor' and 'unsuitable' class for drinking purpose respectively. Islam et al. (2018) assessed the quality of groundwater in Bangladesh using GIS technique and concluded that spatial distribution maps of the investigated region can provide reliable information for policy makers in very sustainable manner. Banerji and Mitra (2018) assessed the groundwater quality of northern Kolkata for drinking purpose based on geographical information system and results of the study predicted that groundwater quality was largely unfit for drinking purpose. Vaiphei et al. (2020) used GIS based technique and water quality index for the groundwater quality assessment in Wanaparthy watershed of Telangana and the results showed that 67.79% of samples pertained to excellent to good water class. Kamaraj et al. (2021) assessed the groundwater quality for drinking and irrigation purpose in Teruchendur of South India using GIS and pollution indices and results inferred that the groundwater was found to be suitable for drinking purpose in the areas closer to the river basin whereas the groundwater was found to be unsuitable for irrigation purpose in more than half of the study area. Amrani et al. (2022) assessed the quality of groundwater for drinking and irrigation purpose in the Timahdite-Almis Guigou area and the results inferred that the groundwater quality was good to poor for drinking purpose while the quality of groundwater was found to be suitable for irrigation purpose. Gubran et al. (2019) used GIS and remote sensing to assess the groundwater quality in Central Saudi Arabia. Adimalla et al. (2022) used GIS tools to assess the suitability of groundwater for drinking purposes in semi-arid region of Southern India and the results indicated that GIS based spatial distribution maps of hydrochemical parameters are very reliable to understand the overall quality of groundwater. GIS can be a prevailing tool to solve problems related to water resources, water quality assessment, determination of water availability, effective management of water resources on local and regional level (Ketata et al. 2011; Sadat-Noori et al. 2013).

In view of above cited literature, GIS based water quality maps has been prepared to assess the quality status of groundwater for drinking and irrigational purpose in parts of NW India specifically Gurdaspur district of Punjab state based on Shannon's Entropy Technique and Irrigational Water Quality Index. The agroeconomic and semi-arid Gurdaspur district utilizes fertilizers and pesticides which intensify the yield of agriculture but poses harmful effect on water quality directly. Continuous overutilization of groundwater for domestic and irrigation usage coupled with anthropogenic activities leads to the deterioration of groundwater quality in the district. Therefore, it is very important to evaluate the quality of groundwater and figure out the hydrogeochemical factors affecting the groundwater chemistry to comprehend the groundwater quality deprivation. GIS based spatial distribution maps will help to identify the groundwater vulnerability zones. Also, GIS based maps will provide benefit to create public awareness and to regulate and implement sustainable water management practices in the study area as well as in the other adjoining agricultural dominant regions of the Punjab which are easy to understand.

Study Area, Geology And Hydrogeology

The area extends between the north latitude 31^0-36' and 32^0-34' and east longitude 74^0-56' and 75^0-24' (Fig. 1). The present study area shares common boundaries with Pathankot district in the north, Beas River in the north-east, Hoshiarpur district in the south-east, Kapurthala district in the south, Amritsar district in the south-west and Pakistan in the north-west. The district is divided into 11 developmental blocks for the administrative control purpose. The climate of the area under investigation is tropical type. The average annual rainfall of the area is 1012 mm in which south western monsoon contributes about 80% of the rainfall. The perennial rivers Ravi and Beas along with their tributaries serves the main drainage of the area. The area of the district is mainly irrigated by tube wells and strong network of canal of Upper Bari Doab canal system from River Ravi.

Geologically, the area of Gurdaspur district is divided into mainly two geomorphological zones; piedmont zone and alluvial zone. Piedmont zone encompasses pebbles, cobbles drain from Siwalik as well as sand of medium to coarse grained gravel. The alluvial plain comprises sand intruded with little clays deposited by rivers of Ravi and Beas. The major aquifer of the area is thick granular zones alternative with thick or thin clay layers. The varying water levels in the Gurdaspur district from 2.39 m bgl to 18–19 m bgl in pre monsoon shows that there is extensive recharge by perennial rivers Ravi and Beas while the water levels fluctuating from 1.70 m bgl to 16.76 m bgl in post monsoon season signifies the declining trend in water levels because of less flow and recharge from the perennial rivers. The net groundwater available in the district is 1837.41 MCM (million cubic metres) and gross draft for all the uses is 2082.08 MCM, hence stage of development is 121%. The overdraft of 244.67 MCM indicates that the groundwater resources are under stress and out of 11 blocks in the district, 6 blocks are over exploited. The less water in an aquifer signifies the increased concentration of ions.

Materials And Methods

Sampling and analytical procedure

For the present research work, altogether 111 groundwater samples covering 11 blocks (Dinanagar, Dorangla, Kalanaur, Dera Baba Nanak, Fatehgarh Churian, Gurdaspur, Dhariwal, Kahnuwan, Qadian, Sri Hargobindpur, Batala) of the district were randomly collected in pre monsoon season (May 2019). The samples were collected after 10 minutes pumping from borewells and handpumps which were mostly installed in the habitant houses and were being consumed for drinking purpose. The collected samples were stored in the precleaned high-density polyethylene (HDPE) bottles with 10% nitric acid and then rinsed with distilled water. The bottles were thoroughly rinsed two times with the water sample to be collected before storing the samples in the pre-processed bottles so as to reduce the chance of impurities. Physical parameters like pH, EC, TDS were determined onsite through Hanna (HI 98194) multiparameter portable water analysis kit. Chemical analysis of major cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) and anions (SO_4^{2-}, NO_3^-, Cl^-, HCO_3^-, F^-) was carried out by using standard method given by APHA 2005. HCO_3^-, Cl^- and TH were determined by titration method. SO_4^{2-}, F^- and NO_3^- were quantified by spectrophotometric techniques. Na^+ and K^+ were measured by the flame photometer. Microsoft Excel 2010 was used to compute basic statistics and IBM SPSS Statistics 25 was used in the chemometric analysis. The accuracy of analysed chemical ions data was calculated using Charge Balance Error (CBE) as given below and values were well within the ± 5% of acceptable limit (Hounslow 1995).

$$\text{CBE (\%)} = \frac{\text{meq / L (Cations)} - \text{meq / L (Anions)}}{\text{meq / L (Cations)} + \text{meq / L (Anions)}} * 100 \quad (1)$$

Estimation Of Drinking Water Quality Based On Shannon's Entropy Technique

The entropy method is used by many researchers to study the groundwater quality (Karunanidhi et al. 2020; Dashora et al. 2021; Li et al. 2021; Kumar and Augustine 2022) and is more realistic than the traditional water quality index method. Shannon's entropy theory was employed to assess the groundwater quality for human consumption as it removes the subjectivity problem and integral ambiguities of groundwater systems. The EWQI method has strong objectivity, and can be used to combine all of the physicochemical data into an illustrative value that effectively reveals the water quality by eliminating human effects while calculating weights. The entropy water quality index was used for the assessment and quantification of groundwater suitability for drinking purposes. It was used to highlight the water quality issues in the study area by increasing the understanding ability of policy makers and general public regarding the water resources and also helps them to frame effective remedial policies if required. The calculations involve five steps:

(1) Establishing an initial evaluation water quality matrix:

If there are 'm' number of groundwater samples, and 'n' number of hydrochemical parameters, then the initial eigen value matrix 'X' can be constructed as shown in following equation:

$$X = \begin{bmatrix} x_{11} & x_{12} \cdots & x_{1n} \\ x_{21} & x_{22} \cdots & x_{2n} \\ \vdots & \vdots \;\; \vdots & \vdots \\ x_{m1} & x_{m2} \cdots & x_{mn} \end{bmatrix}$$

2

(2) Data standardization:

The initial evaluation water quality data vary in dimension and magnitude, and calculated weights are very different. Thus, standardization of initial water quality data is essential and can be carried out using the equation given below:

$$y_{ij} = \frac{x_{ij} - \left(x_{ij}\right)_{min}}{\left(x_{ij}\right)_{max} - \left(x_{ij}\right)_{min}}$$

3

where, $x_{ij}$is the initial matrix; $\left(x_{ij}\right)_{min}$ and $\left(x_{ij}\right)_{max}$ are the minimum and maximum values of the hydrochemical parameters of the water samples respectively. After standardization, the standard matrix y can be obtained as follows:

$$y = \begin{bmatrix} y_{11} & y_{12} \dots & y_{1n} \\ y_{21} & y_{22} \dots & y_{2n} \\ \vdots & \vdots \ \vdots & \vdots \\ y_{m1} & y_{m2} \dots & y_{mn} \end{bmatrix}$$

4

(3) Computing the weight:

The weight is computed by adopting entropy-weight method using following equations:

$$P_{ij} = \frac{y_{ij}}{\sum_{i=1}^{m} y_{ij}}$$

5

$$e_{ij} = \frac{1}{Inm} \sum_{i=1}^{m} P_{ij} In P_{ij}$$

6

$$w_j = \frac{1 - e_j}{\sum_{i=1}^{m} (1 - e_j}$$

7

(4) Determining the quality rating scale:

$$q_j = \frac{C_j}{S_j} \times 100$$

8

$$q_{pH} = \frac{C_{pH} - 7}{8.5 - 7} \times 100 C_{pH} > 7$$

9

$q_{pH} = \frac{7 - C_{pH}}{8.5 - 7} \times 100 C_{pH} < 7$ (10)

where, C_j is the measured concentration of j[th] index; C_{pH} is the measured pH value and S_j is the limit value of World Health Organization (WHO) standards.

(5) Entropy weight calculation:

$$EWQI = \sum_{j=1}^{n} w_j q_j$$

11

Computation Of Base Exchange Indices

Schoeller (Schoeller 1977) has recommended chloro-alkaline indices (CA-I and CA-II) to assess the ion exchange processes within groundwater and its host rock-water interaction environment during its movement and residence time through subsurface. The CA-1 and CA-II were calculated by the equations (all the units are expressed in meq/L) given below:

$CA\text{-}I = \frac{Cl^- - (Na^+ + K^+)}{Cl^-}$ (12)

$CA\text{-}II = \frac{Cl^- - (Na^+ + K^+)}{SO_4^{2-} + HCO_3^- + CO_3^{2-} + NO_3^-}$ (13)

Positive values of CA-1 signify that Na^+ and K^+ ions were exchanged with Ca^{2+} and Mg^{2+} ions in water whereas, ion exchange will be reversed for negative values.

Computation Of Saturation Indices

Saturation status of minerals in groundwater was determined using the hydrogeochemical modelling software PHREEQC (Parkhurst et al. 1999). Saturation indices (SI) of eight minerals namely anhydrite, aragonite, calcite, dolomite, fluorite, gypsum, halite, sylvite was estimated. SI can identify whether precipitation or dissolution has occurred which was computed using the following equation:

$$SI = \frac{K_{IAP}}{K_{SP}}$$

14

where, K_{IAP} is the ionic activity product and K_{SP} is the solubility product. When SI is greater than zero, equal to zero and less than zero, it represents oversaturation (precipitation), equilibrium (saturation), unsaturation (dissolution) state of minerals in groundwater, respectively (Subba Rao et al. 2017).

Chemometric Technique

Chemometric method has been widely applied by many researchers to gain substantial knowledge from the hydrochemical dataset of the groundwater system (Herojeet et al. 2016; Egbueri et al. 2020; Jabbo et al. 2022; Mukherjee et al. 2022). In the present study, chemometric method namely, PCA was applied to understand the possible sources of major cations and anions affecting the groundwater chemistry of the study area. Principal component analysis is a most powerful multivariate data analysis tool for analysing hydrochemical data sets by reducing a large number of original variables to new, uncorrelated smaller set of variables called as principal components. PCA also facilitate the identification of the possible sources/factors affecting the water chemistry and provides a valuable tool for the reliable management of water resources as well as rapid solutions to pollution problems. It makes the process estimation of water quality more viable and efficient as it drastically decreases the efforts, cost and time required for a large number of variables.

The data was standardized by z- scale transformation in order to avoid misclassification due to differences in data dimensionality. Kaiser- Mayer-Olkin (KMO) and Bartlett's tests were applied to examine the suitability of the dataset for PCA. For the better interpretation of the initial factors, varimax rotation was applied in this study. Principal components having the eigen values greater than one was taken and considered significant for explaining the sources of variances in the data (Alberto et al. 2001; Tirkey et al. 2017). The principal components with highest eigen values were considered as most significant. Based on the loading values, the factors loadings were considered as strong, moderate and weak corresponding to the absolute loading values of > 0.75, 0.75 – 0.50 and 0.50 – 0.30 respectively (Liu et al. 2003).

Irrigation Water Quality Index (Iwqi)

The quality of water used for irrigation is vital for crop yield, preservation of soil production and environment protection (Ali and Ali 2018). Irrigation Water Quality Index (IWQI) developed by Meireles et al. (2010) was also used to determine the suitability of water for irrigation purpose. This method helps in the assessment of water quality for irrigation purpose by transforming the large datasets into a single numeric value which apparently elucidates the overall health status of the irrigation water source. Also, it is beneficial for irrigation water managers, field engineers and decision makers to solve problems related to irrigation water quality.

In the IWQI model firstly the dominant and significant parameters which impart important role in the water quality for irrigation purpose must be identified. In this study, five irrigation water quality parameters namely EC, SAR, Na^+, Cl^-, and HCO_3^- were utilised. SAR was calculated using the following equation:

$$\mathbf{SAR} = \frac{Na^+}{\sqrt{\frac{Ca^{2+} + Mg^{2+}}{2}}} \quad (15)$$

In the second step, the individual quality measures (q_i) of each variable and the accumulation witness (w_i) were determined depending upon the value of each individual parameter. Finally, the criteria proposed by Ayers and Westcot (1985) were adopted. In this model higher values are indicator of good water quality and vice versa. The q_i value was calculated on the basis of following equation:

$$q_i = q_{max} - \left[\left(x_{ij} - x_{inf} \right) * q_{imap} \right] / x_{amp}$$

16

Where, q_{imax} is the maximum value of q_i for each class; x_{ij} is the observed value of each parameter; x_{inf} is the corresponding value to the lower limit of the class to which the parameter belongs; q_{iamp} is the class amplitude and x_{amp} is the class amplitude to which the parameter belongs. The upper limit was considered to be the highest value determined in the physicochemical analysis of the water samples (Meireles et al. 2010) to calculate the x_{amp} of the last class of each parameter. Eventually, w_i values were normalized based on following equation:

$$w_i = \frac{\sum_{j=1}^{k} F_j A_{ij}}{\sum_{j=1}^{k} \sum_{i=1}^{n} F_i A_{ij}}$$

17

where, w_i is the relative weight of parameter; F is the constant value of component 1; A_{ij} is the extent to which parameter i can be explained with factor j; i is the number of physicochemical parameters chosen in IWQI and j is the number of factors selected in IWQI. Relative weight of each parameter is shown in Table 1. The q_i values estimated by the University of California Committee of Consultants (UCCC) were used in the study and are shown in Table 2. Hence, IWQI can be calculated as follows:

Table 1
Relative weight of selected parameters based on IWQI

S. No.	Parameters	Relative weight (w_i)
1	EC	0.211
2	Na^+	0.204
3	HCO_3^-	0.202
4	Cl^-	0.194
5	SAR	0.189
	Σw_i	1.000

Table 2
Parameter limit values of selected parameters for the calculation of the quality measure (qi) based on IWQI

Class	q_i	EC (µS/ cm)	SAR $(meq/L)^{1/2}$	Na^+ (meq/L)	Cl^- (meq/L)	HCO_3^- (meq/L)
I	85–100	200 ≤ EC<750	2 ≤ SAR<3	2 ≤ Na<3	1 ≤ Cl<4	1 ≤ HCO_3<1.5
II	60–85	750 ≤ EC<1500	3 ≤ SAR<6	3 ≤ Na<6	4 ≤ Cl<7	1.5 ≤ HCO_3<4.5
III	35–60	1500 ≤ EC<3000	6 ≤ SAR<12	6 ≤ Na<9	7 ≤ Cl<10	4.5 ≤ HCO_3<8.5
IV	0–35	EC < 200 or ≥ 3000	SAR < 2 or ≥ 12	Na < 2 or ≥ 9	Cl < 1 or Cl ≥ 10	HCO_3 < 1 or HCO_3 ≥ 8.5

$$IWQI = \sum_{i=1}^{n} q_i w_i$$

18

where, q_i is the quality of the i^{th} parameter, a number from 0 to 100 and subsequent to function of its concentration and w_i is the normalized weight of the i^{th} parameter and corresponding to the function of its importance in explaining the global variability in water quality. IWQI is dimensionless parameter ranging from 0 to100. IWQI was divided into five classes based on the water quality indexes taking into account the risk of salinity problems, reduction in soil water infiltration and the toxicity to plants.

Gis Technique

Geographical information system (GIS) was used to prepare spatial distribution maps of drinking and irrigational water quality of the study area. Specifically, spatial analyst tool in ArcGIS software (version 10.4.1) was to prepare spatial distribution maps using inverse distance weighted interpolation technique. Present study is a maiden attempt to integrate drinking and irrigational indices along with chemometric techniques using GIS maps in a single study as these are not yet comprehensively addressed by the previous studies in the NW part of India specifically Gurdaspur district. Finally, the outcome of the study will undoubtedly help water managers and decision makers for developing effective management strategies to mitigate the problems related to groundwater quality.

Results And Discussion

Groundwater quality based on physicochemical parameters

Descriptive statistics such as maximum, minimum, mean, standard deviation is listed in Table 3. The concentrations of major ions were compared with drinking water standards BIS (BIS 2012) and World Health Organization (WHO 2011) and are shown in Table 4. The percentage distribution of various parameters concentration in sampled groundwater is shown in Fig. 2 which indicated EC (43.16%) > TDS (28.78%) > Bicarbonate (17.7%) > Magnesium (3.15%) > Calcium (1.42) > Sodium (1.20) > pH (0.40%) Potassium (0.36) > Sulphate (0.3%) > Fluoride (0.01%) trend.

Table 3
Descriptive statistics of analytical parameters of the groundwater samples

WQP	Range		Mean	SD
	Min.	Max.		
pH	7.2	8.68	7.92	0.41
EC (µS/cm)	264	2491	864.5	442.6
TDS (mg/L)	187.4	1644	626	283.8
TH (mg/L)	160	610.5	327	94.6
Mg^{2+} (mg/L)	28	142	62	22
Ca^{2+} (mg/L)	10	110	28	13.9
Na^{+} (mg/L)	0.2	130	23	24.5
K^{+} (mg/L)	0.1	143	7	16.61
HCO_3^- (mg/L)	180	620	351	114
NO_3^- (mg/L)	0	6.95	1	1.68
SO_4^{2-} (mg/L)	1	18	6.8	3.7
Cl^- (mg/L)	15	165	58	31
F^- (mg/L)	0.1	0.4	0.2	0.08

EC is the electrical conductivity; TDS is the total dissolved salts; TH is the total hardness; all the units are in mg/L except EC (µS/cm), pH. WQP is the water quality parameter; Min is the minimum; Max. is the maximum; SD is the standard deviation.

Table 4
Percentage of groundwater samples exceeding limit for drinking purpose as per BIS (2012) and WHO (2011)

WQP	BIS (2012)		WHO (2011)	% of sample above BIS (2012)		% of sample above WHO (2011)
	DL	PL	Standard Value	DL	PL	DL
pH	6.5–8.5		6.5–8.5	11		11
EC	-	1500	1500	-	8	8
TDS	500	2000	1000	51	Nil	7
TH	200	600	500	96	0.9	5
Mg^{2+}	30	100	100	97	8	8
Ca^{2+}	75	200	300	2	Nil	Nil
Na^{+}	-	-	200	-	-	Nil
K^{+}	-	-	12	-	-	14
HCO_3^-	-	-	500	-	-	14
NO_3^-	45	-	50	Nil	Nil	Nil
SO_4^{2-}	200	400	250	Nil	Nil	Nil
Cl^-	250	1000	250	Nil	Nil	Nil
F^-	1	1.5	1.5	Nil	Nil	Nil

All the units are in mg/L except EC (µS/cm), pH. WQP is the water quality parameter; DL is the desirable limit; PL is the permissible limit.

The abundance of major cations followed Mg^{2+} > Ca^{2+} > Na^+ > K^+ trend whereas major anions followed HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- trend respectively. The pH value of groundwater showed a variation from 7.2 to 8.6. Furthermore, 11% of the samples exceeded the permissible limit of 6.5–8.5 as prescribed by BIS (2012) and WHO (2011) indicating alkaline nature of groundwater samples in the region. The spatial distribution of pH (Fig. 3a) indicated the higher values of pH at portions of Dinanagar, Dorangla, Gurdaspur and Dera Baba Nanak blocks. Higher values of pH might be due to the soil and rain water interactions. The levels of EC varied from 264 to 2491 mg/L where 8% of the samples were higher than the permissible limits of 1500 mg/L prescribed by the BIS (2012) and WHO (2011) standards. The spatial distribution of EC (Fig. 3b) indicated the higher values of EC at portions of Dera Baba Nanak, Batala, Kahnuwan, Kalanaur and Fatehgarh Churian blocks. TH is caused by the Ca^{2+} and Mg^{2+} salts dissolved in groundwater. The permissible limit of TH is 600 mg/L as per BIS (2012) and 500 mg/L as per WHO (2011). Results indicated that 0.9% and 5% of the samples were above the permissible limit as per BIS (2012) and WHO (2011) respectively, which is clearly depicted in Table 4.

Mg^{2+} concentration in the study area ranged from 21 to 142 mg/L. A total of 8% of samples surpassed the permissible limit of 100 mg/L as per BIS (2012) and WHO (2011). The spatial distribution of Mg^{2+} (Fig. 3d) indicated the higher values of Mg^{2+} at portions of Dera Baba Nanak and Qadian blocks. Concentration of Ca^{2+} varied from 10 to 110 mg/L and all the samples were within the permissible limit. The spatial distribution of Ca^{2+} (Fig. 3e) indicated the higher values of Ca^{2+} at eastern side of the study area. The mean concentration of Na^+ was 23 mg/L, where all the samples were within the permissible limit of 200 mg/L prescribed by the WHO (2011) standards. The concentration of K^+ in 14% of the samples were above the permissible limit of 12 mg/L as per WHO (2011). The spatial distribution of K^+ (Fig. 3f) indicated the higher values of K^+ at portions of Dera Baba Nanak, Kahnuwan. Dhariwal, Qadian and Kalanaur blocks. The higher concentration of K^+ was might be due to the fertilizer applications and may lead to nervous system damage. The HCO_3^- ion concentration varied from 180 to 620 mg/l, where a total of 14% of the samples surpassed the permissible limit of 500 mg/L as per WHO (2011). The spatial distribution of HCO_3^- (Fig. 3c) indicated the higher values of HCO_3^- at portions of Dera Baba Nanak, Sri Hargobindpur and Kalanaur blocks. The values of SO_4^{2-}, F^- and NO_3^- and Cl^- were within the permissible limit prescribed by BIS (2012) and WHO (2011) standards.

Drinking Water Quality Assessment Based On Ewqi

The values of EWQI in the study area ranged between 12.12 to 476.39 and the classification and percentage distribution of sampled groundwater using EWQI is presented in Table 5. Generally, water with EWQI values > 100 is unsuitable for drinking purpose (Wu et al. 2018; Suba Rao et al. 2020). The results of the study indicated that 4 groundwater samples collected from blocks; Dera Baba Nanak, Kalanaur, Kahnuwan and Dhariwal were categorised as extremely poor water quality, which are not recommended for drinking usage. Furthermore, one sample collected from Dhariwal block was categorised as poor water quality, which is also not recommended for drinking usage. 13.5% of the samples were found to be in medium water class, which shows that this water is marginally suitable for drinking purpose. Therefore, pre-treatment of medium quality water is recommended before its consumption for drinking purpose. Approximately, 43.24% and 38.73% of the samples were found to be in excellent and good water class, which indicates that water is suitable for drinking purpose. The spatial distribution GIS map (Fig. 4) based on EWQI estimations, indicated that poor to extremely water quality was encountered in the blocks; Dera Baba Nanak, Kalanaur, Kahnuwan and Dhariwal.

Table 5
Classification of analysed groundwater samples based on EWQI values

Class	Rank	Water quality	Groundwater samples	
			No. of samples	% of samples
< 25	I	Excellent quality	48	43.24
25–50	II	Good quality	43	38.73
50–100	III	Medium quality	15	13.51
100–150	IV	Poor quality	1	0.90
> 150	V	Extremely poor quality	4	3.60

As the area under investigation is agriculture dominant, usage of agrochemicals for various agricultural activities might be the cause of poor to extremely poor drinking water quality. Therefore, the treatment of groundwater is necessary in the areas having poor to extremely poor drinking water category before the utilization to avoid the suffering of general public from various water borne diseases.

Hydrogeochemical Facies And Water Types

Piper's tri-linear diagram (Piper 1944) has been widely used to understand the hydrogeochemical regime of a study area. The results of the piper diagram (Fig. 5) indicated that the majority of the samples fall under Ca^{2+}-Mg^{2+}-HCO_3^- type which is considered for drinking water suitability. It also revealed that Ca^{2+} - Mg^{2+} (Alkaline earths) exceeded Na^+- K^+ (Alkalies) and HCO_3^- - CO_3^{2-} (Weak acids) exceeded Cl^- - SO_4^{2-} - F^- (Strong acids). Only 1 sample was under Na^+- K^+- HCO_3^- type. Further, cation triangle showed that the Mg^{2+} was the principal ion which might be due to the presence of evaporite deposits and dolomitic rocks. Only 7 samples fall under no dominant type whereas, one sample fall under sodium type. Anions triangle represents that the HCO_3^- is the dominant anion. The increased concentration of HCO_3^- in the study area is might be due to the agricultural return flow and bacterial oxidation of organic matter. Ca^{2+}-Mg^{2+}-HCO_3^- type waters are characterised by temporary hardness and it shows that groundwater is being recharged. The foremost processes associated with Ca^{2+}-Mg^{2+}-HCO_3^- are rock weathering, mineral dissolution and ion exchange.

Base Exchange Indices

In the present study, 72% of sampled groundwater showed positive values for both CA-I and CA-II, emphasizing that Na^+ and K^+ ions were replaced by Ca^{2+} and Mg^{2+} ions, indicating reverse ion exchange processes which resulted in the increase of Ca^{2+} and Mg^{2+} concentration in the groundwater. However, 27.9% of samples showed negative values for both CA-I and CA-II indicating cation exchange processes which may cause increase of Na^+ concentration in groundwater. The relationship between CA-I and CA-II were further plotted to discriminate the reverse ion exchange processes, as shown in Fig. 6. It can be seen that majority of the sampled groundwater fell top right of the plot, indicating reverse ion exchange, which lead to the enrichment of Mg^{2+} concentration in the groundwater.

The role of reverse ion exchange processes in the hydrogeochemistry of sampled groundwater was further confirmed by plotting Ca^{2+} + Mg^{2+}-SO_4^{2-}-HCO_3^- vs Na^+-Cl^- (Fig. 7). Around 81% of the sampled groundwater fell in the reverse ion exchange zone and 16.21% of the sampled groundwater fell in the cation exchange zone. Remaining sampled groundwater points fell away from the equiline, signify the influence of anthropogenic activities on groundwater chemistry (Kumar et al. 2020; Marghade 2020; Karunanidhi et al. 2020).

Saturation Indices

SI of eight minerals namely anhydrite, aragonite, calcite, dolomite, fluorite, gypsum, halite, sylvite was estimated and is shown in Fig. 8. All sampled groundwater showed SI values greater than zero for aragonite, calcite and dolomite indicating their oversaturation (precipitation) state. However, the SI of anhydrite, fluorite, gypsum, halite and sylvite were less than zero indicating that sampled groundwater was unsaturated with respect to these minerals. The SI of sampled groundwater indicated that carbonate minerals tend to precipitate and evaporative minerals were in undersaturated state.

Chemometric Technique

For sampled groundwater, the first three rotated factors with eigen value greater than 1 were extracted and represented 72.89% of the entire data variability (Table 6). Factor 1 (PC1) defined total variance of 33.12% and showed strong positive loading with EC, TDS, magnesium, TH and bicarbonate contributing to temporary hardness of water and dissolution of magnesium rich rocks by weathering processes. High EC and TDS indicated anthropogenic activities in the study area. The combination of total hardness and bicarbonates indicated the salinity environments of groundwater reserves (Das and Nag 2017). Factor 2 (PC2) accounted total variance of 27.16% and showed moderate positive loading with potassium indicating domestic activities and applications of fertilisers for various agricultural activities. Factor 3 (PC3) defined 12.61% of the total variance and showed moderate positive loading with calcium and magnesium indicating weathering of calcite and dolomite rich minerals.

Table 6
Varimax rotation component matrix of analysed sampled groundwater

Variable	PC1	PC2	PC3
Varimax rotated (n = 111)			
pH	-0.277	0.495	0.384
EC	**0.903**	0.269	-0.121
TDS	**0.903**	0.269	-0.121
Ca^{2+}	0.140	-0.363	-0.585
Mg^{2+}	**0.780**	-0.348	0.510
TH	**0.803**	-0.469	0.276
Na^{+}	0.616	0.189	-0.394
K^{+}	0.514	0.631	0.143
HCO_3^-	**0.823**	-0.248	0.081
Cl^-	**0.741**	0.152	-0.154
Eigen value	3.312	2.716	1.261
Variance (%)	33.117	27.164	12.610
Cumulative (%)	33.117	60.281	72.891

Irrigation Water Quality Assessment Based On Iwqi

The calculated IWQI values varied from 34.76 to 77.09 and the classification of groundwater samples based on the IWQI is given in Table 7. The results of IWQI indicated that 3 groundwater samples were placed in ‘severe restriction’ class and it is not recommended to use this water for irrigation purpose under normal conditions. Approximately 65 groundwater samples were placed in ‘high restriction’ class, which can be used in soils with extreme permeability without compact layers. Almost 41 samples were placed in ‘moderate restriction’ class, which can be used for soils with moderate to high permeability. Therefore, it is highly recommended to adopt moderate leaching of salts so as to avoid soil degradation problem in this case. Approximately 2 samples were placed in ‘low restriction’ class. Hence, leaching of soil is recommended to avoid sodicity of soil in heavy textures. None of the groundwater samples were placed in ‘no restriction’ class.

Table 7
Classification of analysed groundwater samples based on IWQI values

Class	Exploitation restrictions	Groundwater samples	
		No. of samples	% of samples
85–100	No restriction	Nil	Nil
70–85	Low restriction	2	1.80
55–70	Moderate restriction	41	36.93
40–55	High restriction	65	58.55
0–40	Severe restriction	3	2.70

The spatial distribution GIS map (Fig. 9) based on IWQI estimations, indicated that the almost whole district exhibited moderate to high restriction irrigation water quality class. ‘Severe restriction’ class was encountered in portion of blocks; Dera Baba Nanak and Fatehgarh Churian. The effluents carried out by the Ravi River which enters Dera Baba Nanak block of India from Narowal district of Pakistan, might be the cause behind the deteriorating irrigation water quality. Leaching of elements from gypsum rocks might be the reason behind the elevated concentration of EC and TDS in the study area. In addition, overexploitation of groundwater and excessive usage of agrochemicals for agricultural purpose might be another reason of degrading irrigation water quality in the area under investigation.

Conclusion

The primary aim of the present study was to assess the quality of sampled groundwater and also check its suitability for drinking and irrigation purpose in agrarian parts of NW India. Dominance of magnesium and calcium as major cations whereas bicarbonate and chloride as major anions, revealed that weathering of silicate minerals and ion exchange processes were prevalent activities in the study area. Among different hydrochemical parameters pH, EC, TDS, TH, Mg^{2+}, HCO_3^-, K^+ were found to be beyond permissible limit in some of the sampled groundwater. Fluoride concentrations in the entire study area were found to be lower than the standard required value of 0.5 mg/L therefore extra amount of fluoride may added in groundwater utilized for drinking purpose to help prevent tooth decay in children. The results of EWQI inferred that the groundwater quality was not suitable for drinking purpose particularly in parts of Dera Baba Nanak, Kalanaur, Kahnuwan and Dhariwal blocks. Therefore, the population living in areas having high EWQI values are at high risk in terms of potential health effects from consuming the direct contaminated groundwater. Mineral saturation index indicated that carbonate minerals were oversaturated and the evaporative minerals were undersaturated. The findings of the PCA exhibited that the ion exchange, weathering of aquifer material and anthropogenic influx from agricultural activities were the dominant controlling processes in the study region. From the results of IWQI for irrigation purpose, it has been found that majority of groundwater samples were under high to moderate restriction class. It is pertinent to mention that groundwater quality was found to be unsuitable for drinking and irrigation purpose particularly in the blocks which are closer to the Indo-Pak international boundary and this might be due to the domestic, irrigational and industrial effluents carried out by the River Ravi which enters into Dera Baba Nanak block of India from Narowal district of Pakistan. Continued utilization of this water for drinking and irrigation purpose may cause health issues, salinization problems and can pose harmful effects on the crop productivity. Therefore, it is highly recommended to adopt appropriate planning and policies of drinking and irrigation water management so that good quality of drinking and irrigation water can be provided to local people and farmers in the study area. The outcomes of this study will be useful for the policy makers to aware the local people and farmers regarding the status of groundwater contamination for drinking and irrigation use in the study area as clean drinking water is a key to good human health and increased agricultural productivity. The study recommends the adaptation of remedial actions particularly in the regions where drinking and irrigational groundwater quality issues are reported to ensure clean and suitable drinking water for the inhabitants. Further studies pertaining to isotopic analysis are needed to appraise the hydrogeochemistry of the study area.

Declarations

Acknowledgements The authors are grateful to the Department of Environment Studies and Geology, Panjab University Chandigarh for providing necessary research facilities during this work.

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent to publish Not applicable.

Authors Contributions Ashima Awasthi: conceptualization, field work, sampling, testing, data interpretation, software, writing original draft, review and editing; Madhuri S. Rishi: conceptualization, final review, editing and supervision; Ashu Khosla: conceptualization, review and supervision; Shivali Panjgotra: conceptualization, testing and investigation.

Funding The first author has received funding under Panjab University Ph.D. Research Scholarship.

Competing interests The authors declare no competing interests.

Availability of data and materials The datasets used during the current study are available from the corresponding author on reasonable request.

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Figures

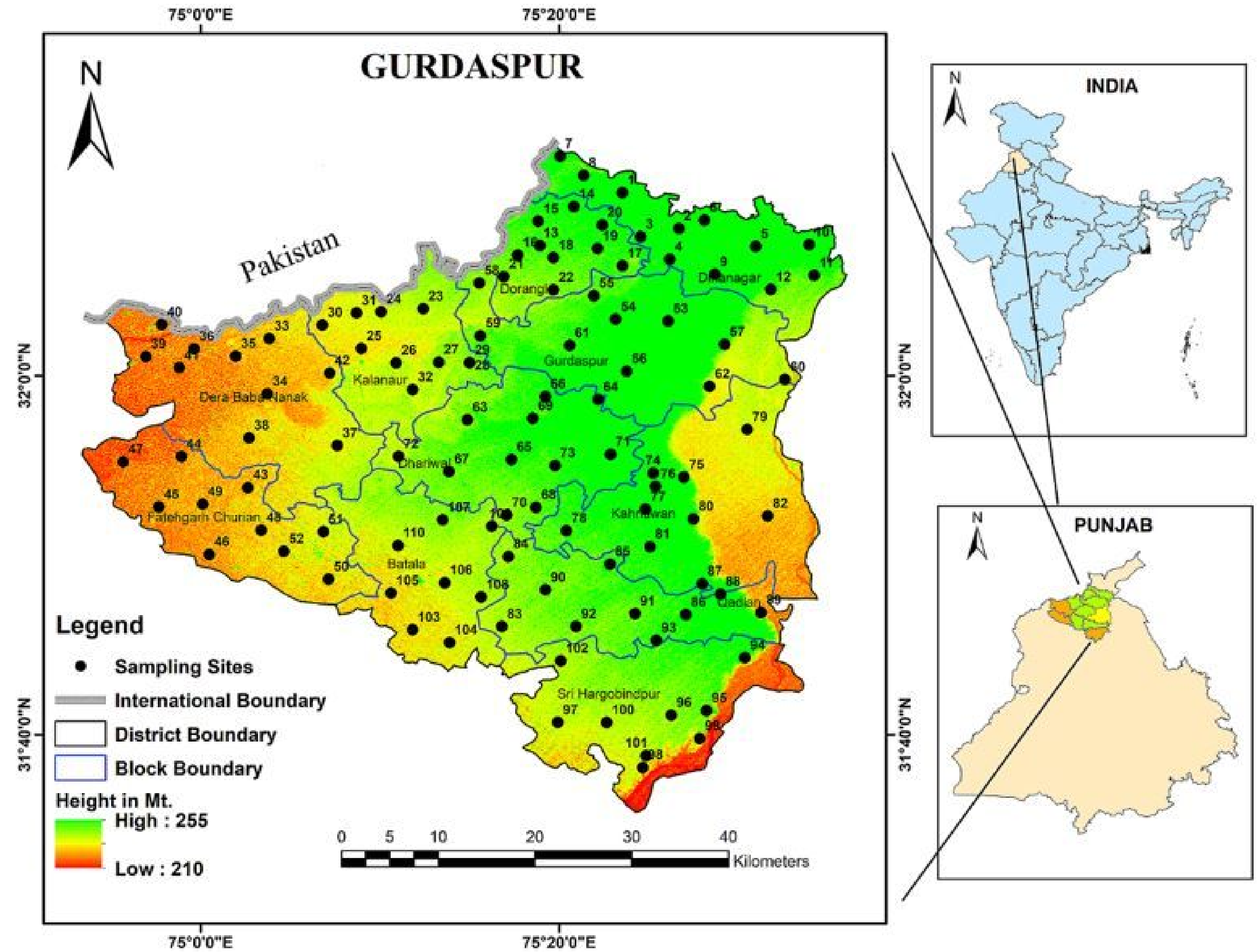

Figure 1

Location map of study area with groundwater sampling points

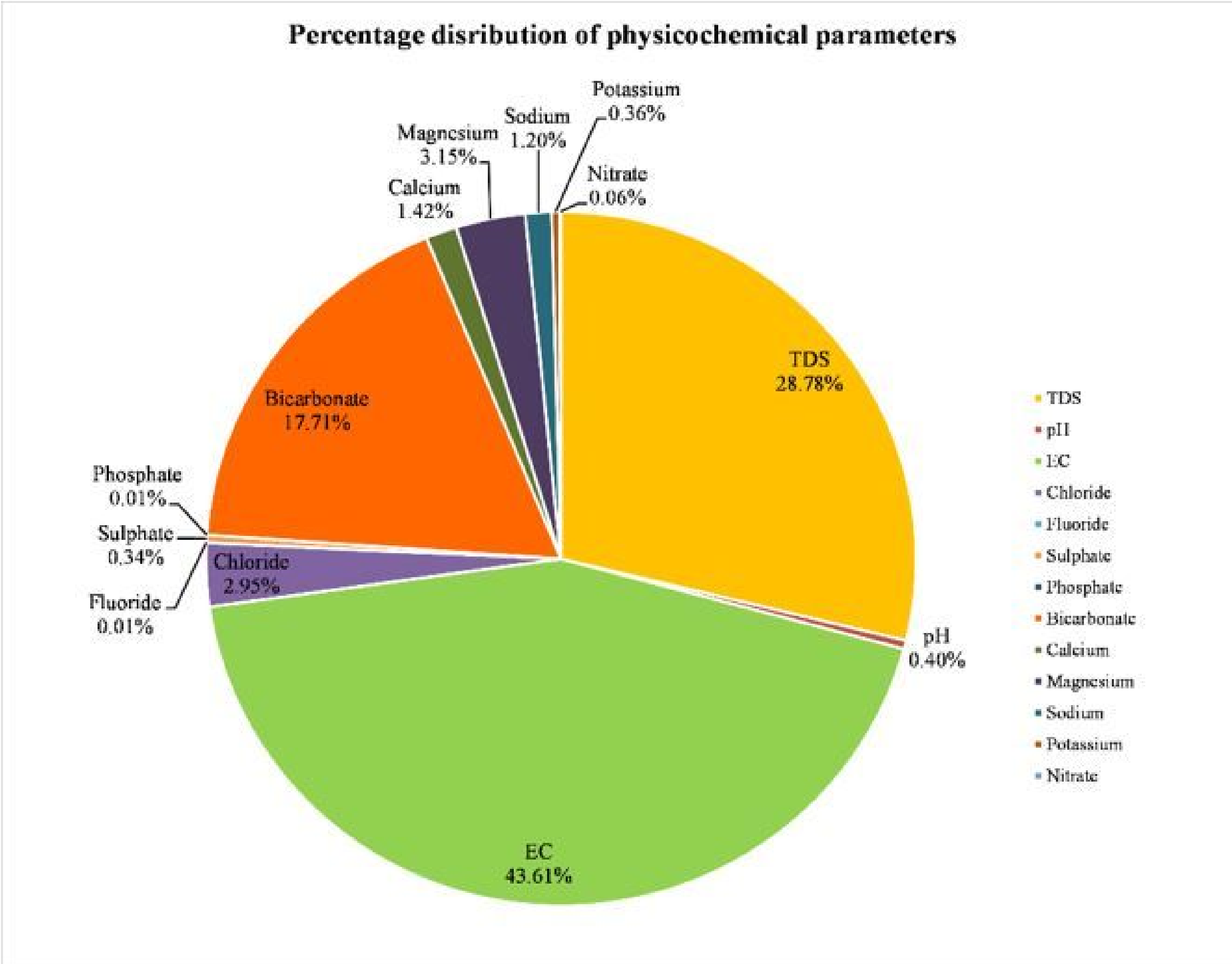

Figure 2

Pie chart showing percentage distribution of analysed physicochemical parameters

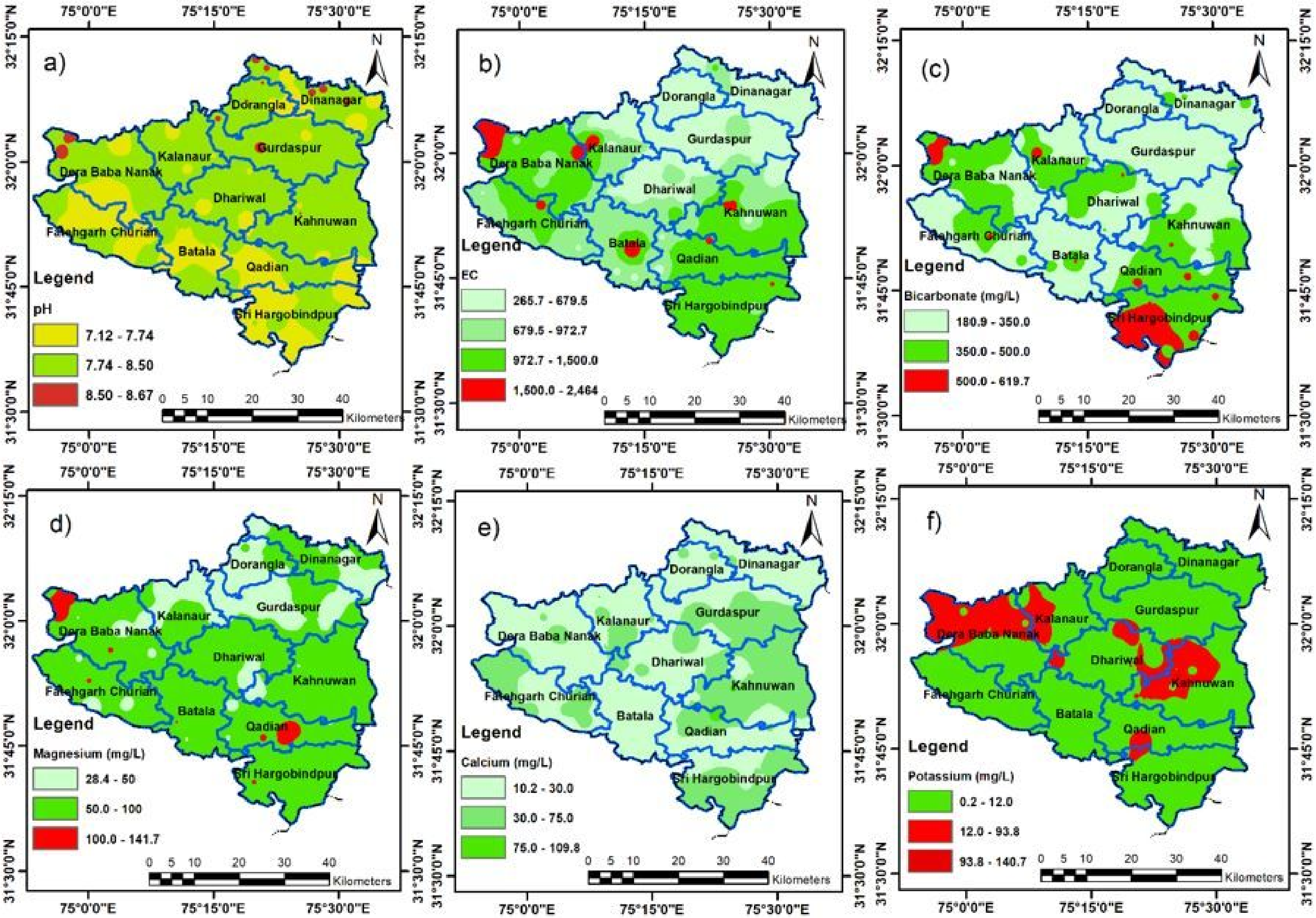

Figure 3

Spatial distribution maps of some water quality parameters in the study area; **a** pH; **b** EC; **c** Bicarbonate; **d** Magnesium; **e** Calcium; **f** Potassium

Figure 4

Spatial distribution of drinking groundwater quality based on EWQI

Figure 5

Piper diagram representing hydrochemical facies of groundwater

Figure 6

Binary plot of CAI-I vs CAI-II explaining reverse ion exchange process in the groundwater

Figure 7

Binary plot of $Ca^{2+} + Mg^{2+}$-SO_4^{2-}-HCO_3^- vs Na^+-Cl^-

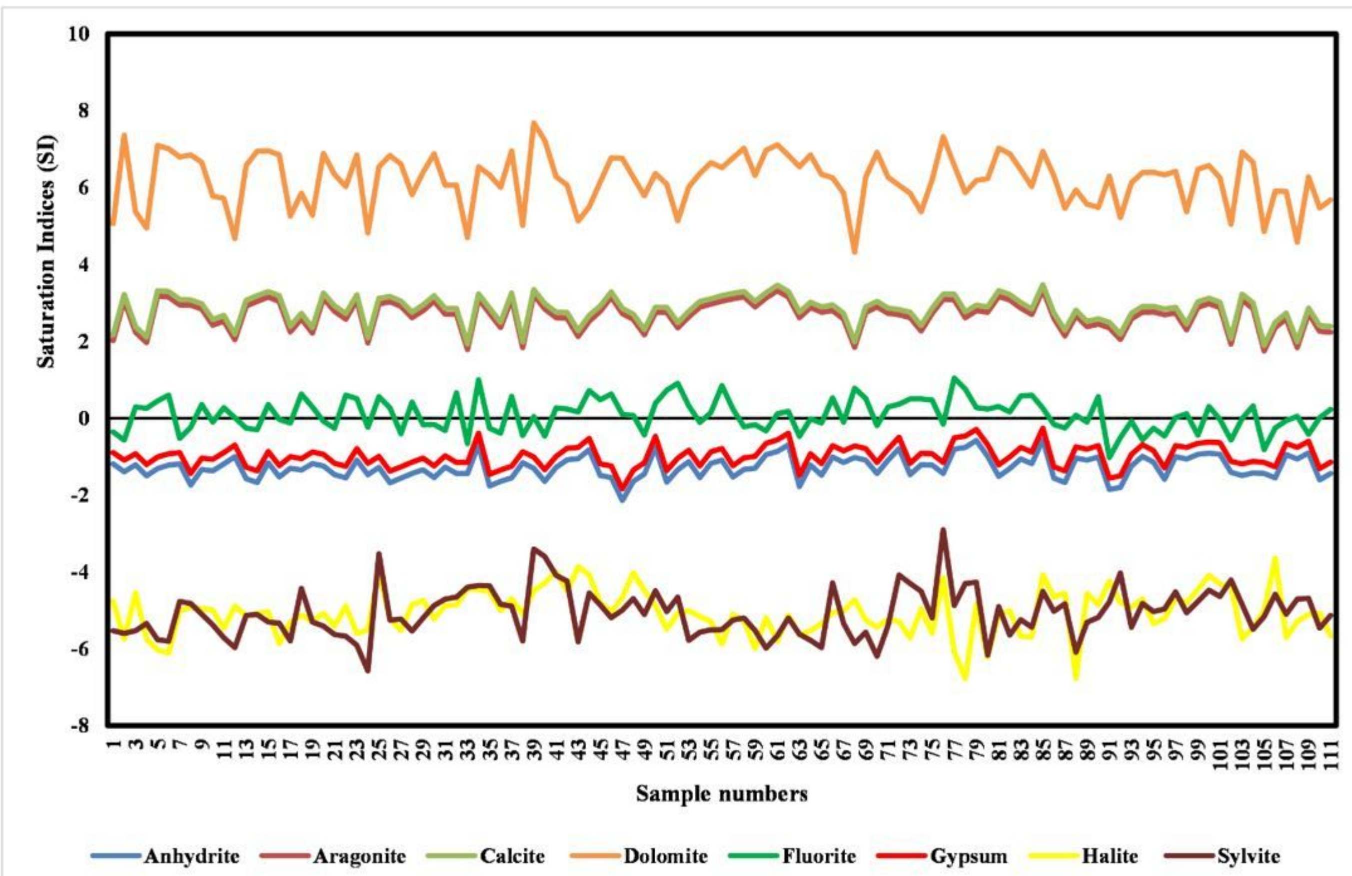

Figure 8

Saturation indices of analysed minerals in the groundwater

Figure 9

Spatial distribution of groundwater quality based on IWQI