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# Hydrogeochemical characterization of groundwater in alluvial plains of river Yamuna in northern India: An insight of controlling processes

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## ABSTRACT

Groundwater chemistry of an aquifer is influenced by several physical and chemical factors as well as their inter-ionic relationship prevailing in any area. To assess the factors influencing the chemical composition of groundwater in Panipat district, Haryana, India, a semi-arid alluvial region, different parameters including potential hydrogeochemical weathering as well as their ionic indices and conventional graphical methods were employed. The groundwater analysis data did not explicitly show the dominance of a single rock mineral dissolution process. The inter-ionic relationship between $Ca^{2+}$+$Mg^{2+}$ and $SO_4^{2-}$ + $HCO_3^-$ also indicated that the carbonate and silicate weathering were invariably prevailing in the region. The chloro-alkali indices have shown that $Ca^{2+}$ and $Mg^{2+}$ were replaced by $K^+$ and $Na^+$ of surrounding aquifer rock material in 51.1% of groundwater samples. However, there were strong indications of the influence of reverse ion exchange in rest of the data. The piper diagram represented the $Ca^{2+}$-$Mg^{2+}$-$Cl^-$-$SO_4^{2-}$ type water, indicating an excess of alkaline earths over alkalies ($Ca^{2+}$ + $Mg^{2+}$ >$Na^+$ +$K^+$) and excess of stronger acidic anions over the weaker acidic anions ($Cl^-$+ $SO_4^{2-}$ > $CO_3^-$+$HCO_3^-$). The factor analysis indicated that the weathering of aquifer rock material and anthropogenic activities are the main controlling factors in the region.

## 1. Introduction

Groundwater is an essential source for human due to its widespread availability and good quality. Globally, groundwater is a prominent source for irrigation, domestic and industrial supply in semi-arid provinces. Previous studies revealed that 65% of the global domestic water supply comes from groundwater, for irrigation it accounts for 20% and for industrial purposes around 15% (Adimalla et al., 2018). The groundwater quality in a region depends upon the geochemical composition of underlying rock strata, quality of recharge water, soil and water interaction processes, soil and gaseous phase interaction, rocks present in the unsaturated zone and their interaction with recharge water, residence time in aquifer and processes taking place in the aquifer itself (Freeze and Cherry, 1979).

Worldwide, agriculture is one of the major groundwater consumer and nowadays higher groundwater draft significantly altering the landscape. Geomorphologically, alluvial plains are the most vital and fertile landscapes used for high agricultural productivity (Verhoeven and Setter, 2009). Groundwater levels and quality always tend to vary, some changes are due to natural phenomenon and some are induced because of mankind. During summer season extraction of large quantities of groundwater from these aquifers adversely affect its quantity, quality and recharge which further alters the surface and groundwater interactions in alluvial regions (Lepure et al., 2014). In unconfined alluvial aquifers, groundwater is externally vulnerable to contamination due to surface and groundwater interaction. The fate, as well as the impact of agricultural and industrial chemical residue discharge, is principally a function of hydrogeochemistry of the region (Paudel et al., 2015). Thus, hydrogeochemical characterization and geological information of the aquifer system is important for the management of the resource (Howarth, 2013). The assessment of the groundwater system and hydrogeochemical processes responsible for its quality provides an insight into the comparative influences of rock-water

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interaction and human-induced alterations. Excessive natural resource exploitation and high waste generation in modern society also threaten groundwater quality in many regions.

Traditionally, India is an agricultural dominant country and groundwater is one of the most important sources of irrigation. Nearly 50–80% of irrigation in India is under groundwater command and 90% of rural inhabitants and more than 50% of the urban population's water demands are fulfilled by groundwater (CGWB, 2013a,b). Groundwater depletion due to over-extraction for irrigation, industrial and other activities and alteration in its quality due to contamination and pollution resulting from industrial expansion, urbanization, unsystematic use of chemical fertilizers and pesticides in agriculture, waste disposal, insufficient drainage etc. are the great concerns in India. Such hydrogeochemical, as well as anthropogenic contamination processes responsible for the groundwater quality of a region, can be statistically analyzed. The multivariate statistical techniques are proved beneficial because of their relative significance in assessing large chemical dataset (Prasanna et al., 2010; Bouderbala, 2017; Ravikumar and Somashekar, 2017; Herojeet et al., 2017; Aghazadeh et al., 2017; Wu et al., 2017; Srivastava and Ramanathan, 2018; Gopinath et al., 2018; Rajkumar et al., 2018).

Panipat is one of the main hubs of the textile industry in India. Panipat has numerous large, medium and small cloth/thread dye houses along with a thermal power station, petroleum refinery, sugar mills and fertilizer processing plant providing livelihood to many people but it cannot be denied that these industries generate huge amounts of toxic wastewater too. The dimensions of urbanization and industrialization are increasing rapidly in the region and most of the medium to small-scale industries dispose off their wastewater without proper treatment on nearby land or in unlined drains. Further, maximum geographical area is under agricultural command, the unregulated use of fertilizers and pesticides along with unscientific industrial wastewater disposal may contribute to the changing hydrogeochemistry of the region as alluvial aquifers are the most vulnerable to contamination. Thus it is important to study the hydrogeochemical processes controlling the aquifer geochemistry. The aim of the present investigation is to evaluate the major hydrogeochemical processes influencing the aquifer chemistry in Panipat district of Haryana, India where the majority of the population is dependent on the groundwater for various uses.

## 2. Description of the study area

Panipat is an agricultural cum industrial district of Eastern Haryana, India. Its geographical extent extends from 29°10′15″:29°30′25″ North to 76°38′30″:77°09′15″ East (Fig. 1). It occupies nearly 1263 km$^2$ area. River Yamuna flow throughout its eastern edge and serve as a natural boundary between the state of Haryana and Utter Pradesh. The climate of the study area is the semi-arid type and receives maximum rainfall during the monsoon period i.e. July to September each year.

The surface water resources in the region are usually precarious as they do not receive water for irrigation in the non-monsoon season and the local population mostly employs groundwater obtained from privately owned wells for irrigation, domestic and industrial purposes (CGWB, 2013a,b). About 80% of the geographical area is under the influence of agricultural activities, and the majority of the remaining area is dominated by urban-rural built up inhabitation and industrial setup. According to Haryana Pollution Control Board classification (no. of industries per 10 km$^2$), the area study area has six highly polluting, 413 red

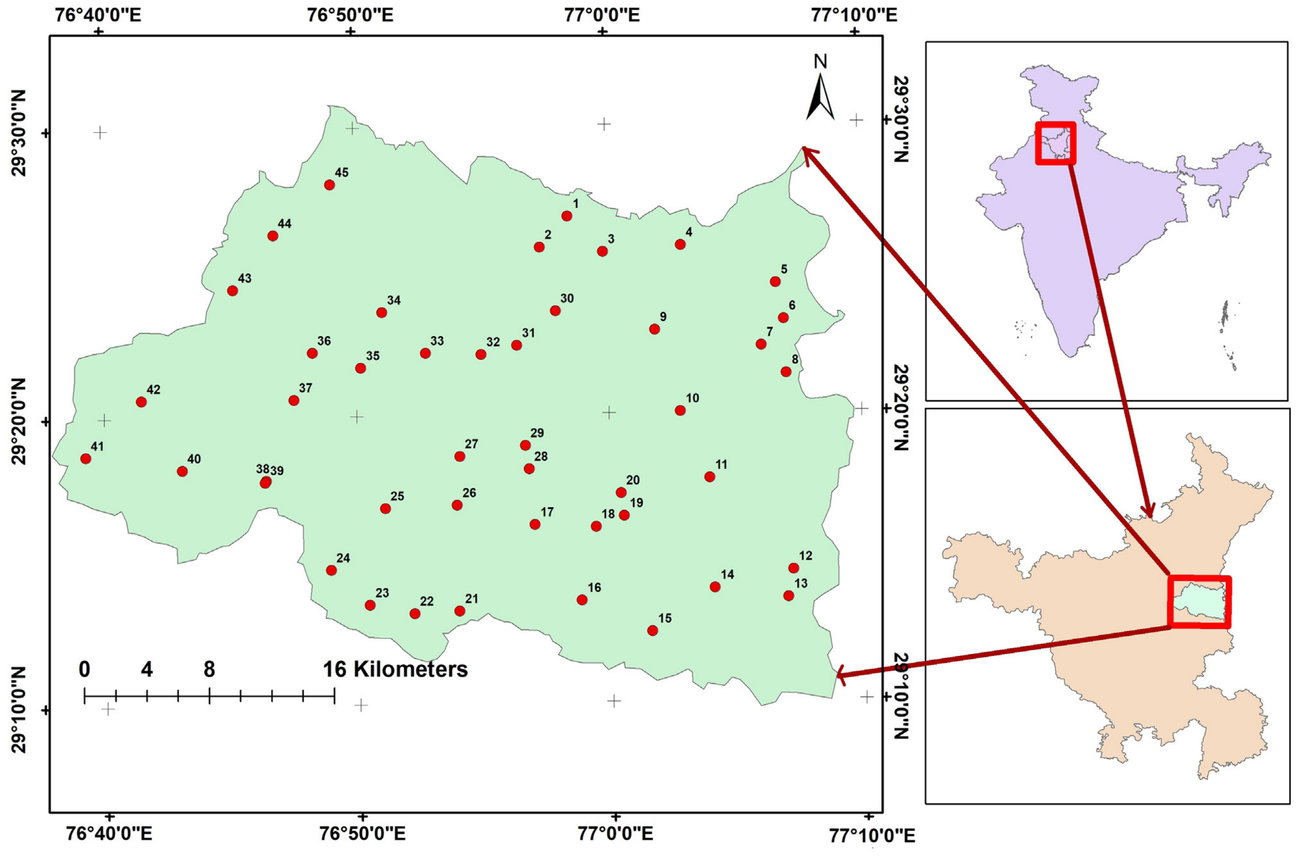

**Fig. 1.** Location Map of Study Area, District Panipat, Haryana, India.

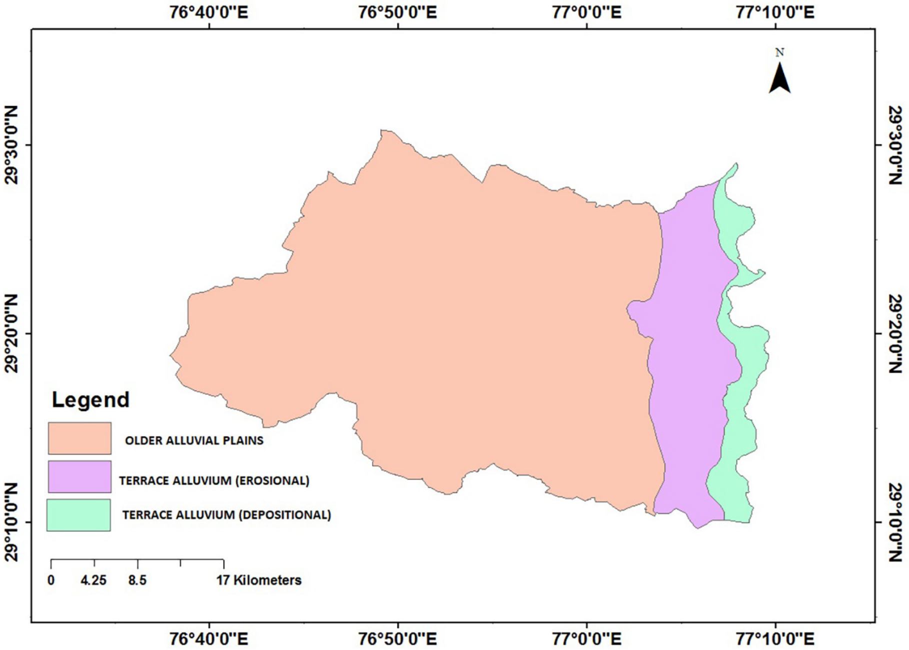

**Fig. 2.** Geology of district Panipat Haryana, India (taken from CGWB).

categories, 1145 orange and green categories and 10 grossly polluting industries.

### *2.1. Geological and hydrogeological setting*

The study area has almost homogenous geological nature and is completely covered by old and new alluvium deposits of Quaternary to Recent age, consisting of clay and sand. The geology of the region is shown in Fig. 2 indicating maximum area under older alluvium whereas newer terrace alluvium of erosional and depositional origin is present towards the eastern edge. Geological formations present in the area are of Quaternary age which comprises of recent alluvial deposits of the vast Gangetic alluvial plains. The whole district comprises of 8–23 granular zones up to a maximum depth of 260 m below ground level (m bgl) (CGWB, 2013a,b). Sand and gravel of varied size constitute these granular zones. The first aquifer occurs between 50 and 150 m bgl, the second one extends from 130 to 250 m bgl and the third one lies between 286 and 366 m bgl. The discharge rate of aquifers in the area ranges from 605 to 3258 Litre Per Minute (LPM). The aquifer holds a transmissivity range between 350–1990 $m^2$/day (CGWB, 2013a,b). The groundwater development in the whole district surpassed the available recharge and is categorized as over-exploited with a groundwater development stage of 167%. Total available net annual replenishable groundwater is 308.65 MCM (million cubic meters) and total draft for all uses in Panipat is 514.56 MCM, thus parting short-fall (overdraft) of 205.91 MCM indicating that the groundwater resource is under stress and the water level is declining (CGWB, 2013a,b). The groundwater level trend in Panipat is showing continuous decline and the area may suffer from water shortage in near future (Kaur and Rishi, 2018).

## 3. Materials and methods

A total of 45 samples were collected during post-monsoon season in the year 2015 from the study area after pumping for 10 minutes and the collected samples were stored in pre-washed HDPE bottles. Hanna (HI 98194) multi-parameter potable water testing kit was used to measure onsite parameters namely electrical conductivity (EC), total dissolved solids (TDS) and pH. The water quality analyses were performed by following the standard method given by APHA (2005). The results of the above said parameters were analysed statistically as well as graphically by using Microsoft Excel 2007, Minitab 18 and Rockworks 2015 software. Various spatial distribution maps along with sampling location map were prepared by using software ArcMap 10.4.1.

For the present assessment cation–anion balance, inter-ionic relationships, Chloro-Alkaline Indices (CAI), Piper diagram and Chadha's diagram were employed to evaluate the chemical composition of groundwater in the study area.

The results of groundwater quality parameters were further selected for factor analysis. Principal Component Analysis (PCA) was employed to obtain the correlation matrix of the original variables data (Wu et al., 2014; Rajkumar et al., 2018). The criteria adopted for the selection of a number of factors was on the basis of eigen value >1(Kaiser, 1958). Varimax method was selected for the orthogonal rotation of the original factors to terminal factors as it makes the best use of the variance of the loadings on the factors and adjusts them closer to −1 to +1 or near 0. This method maximizes the variance of squared loadings within factors (Prasanna et al., 2010). The factor score coefficients were obtained from the factor loadings. For each water sample, the factor scores were determined by multiplying a factor score coefficient matrix with standardised data. Every individual factor score value expresses the significance of a specific factor at the sampling location. Factor score value +1 or more signifies strong influence by the process whereas the negative factor score values of the water samples were characterized as samples with non-representative scores indicating areas nearly unaltered by the process and the nearer to 0 signifies areas with the moderate influence of the process.

## 4. Results and discussion

The cation–anion balance of the samples ranged within 0–5%, indicating the acceptability of the laboratory analysis results for the present study. The summary statistics of quality parameters

**Table 1**
Summary statistics of Physico-chemical quality parameters of groundwater samples of Panipat District.

| Parameter | Unit | Minimum | Maximum | Mean | Standard deviation |
|---|---|---|---|---|---|
| n = 45 | | | | | |
| pH | – | 7.29 | 8.89 | 8.01 | 0.345 |
| TDS | mg/L | 260 | 2160 | 701.24 | 429.13 |
| EC | µS/cm | 433.3 | 3600 | 1168.73 | 715.21 |
| $Cl^-$ | mg/L | 18 | 380 | 171.20 | 107.89 |
| $SO_4^{2-}$ | mg/L | 30 | 390 | 129.69 | 98.68 |
| $NO_3^-$ | mg/L | 1.19 | 112 | 22.37 | 18.59 |
| $HCO_3^-$ | mg/L | 195 | 940 | 469.84 | 194.77 |
| $CO_3^-$ | mg/L | 0 | 50 | 5.04 | 11.09 |
| $Ca^{2+}$ | mg/L | 13 | 157 | 68.29 | 32.97 |
| $Mg^{2+}$ | mg/L | 10 | 90 | 32.00 | 17.94 |
| $Na^+$ | mg/L | 15 | 613 | 151.87 | 174.28 |
| $K^+$ | mg/L | 0.9 | 45 | 9.46 | 7.81 |
| TH | mg/L | 64 | 750 | 340.58 | 155.89 |

for the groundwater samples is given in Table 1**.** The mean concentration of the anion followed $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^-$ trend whereas cations followed $Na^+ > Ca^{2+} > Mg^{2+} > K^+$ trend. The pH of the groundwater ranged from 7.29 to 8.89 with mean value of 8.01 indicating majority of the samples representing alkaline nature (Table 1). The TDS value ranged between 260 and 2160 mg/L having mean value of 701.24 mg/L (Table 1) indicating majority of the samples as freshwater whereas the total hardness for the groundwater samples ranged from 64 to 750 mg/L with a mean value of 340.58 mg/L.

### *4.1. Ionic interactions*

Rock weathering process is one of the main processes to control the geochemical cycling in the aquifer system (Berg, 1932). The nature and rate of chemical weathering differ significantly depending on the interlinked variables together with bedrock type, the topography of the area, climatic system and biological activities taking place in the area. Inter-ionic relationships of various cations versus anions have been plotted to assess their sources (common or varied) to understand the present chemical composition of groundwater.

$Na^+$ and $Cl^-$ are important naturally present ions and if sodium present in the groundwater is derived from halite weathering, the sodium and chloride concentrations should be very closely aligned with the 1:1 line of $Na^+$ versus $Cl^-$ plot (Tiwari and Singh, 2014; Aghazadeh et al., 2017). In the present study, most of the groundwater samples do not fall along the 1:1 equiline. Hence, it is clear from the plot (Fig. 3(a)) that sodium and chloride chemistry in the region cannot be explained only on the basis of halite dissolution processes because halite dissolution releases almost equal quantities of sodium and chloride into the solution. Meybeck (1987) reported that if the $Na^+/Cl^-$ ratio in water is greater than 1, the source of $Na^+$ is silicate weathering whereas approximately 1 indicates halite dissolution. In the present investigation, the observed average Na/Cl ratio of 2.23 in groundwater samples was greater than the standard marine/seawater mean value of 0.85 suggesting that higher concentration of sodium may be added from weathering of rocks or anthropogenic activities as compared to atmospheric precipitation (Aghazadeh et al., 2017). 48.9% of the groundwater samples were derived from other clay minerals (Fig. 3(a)) such as sodium montmorillonite, sodium aluminium silicate or albite aluminium silicate as in Eqs. (1) and (2) respectively.

$$3Na_{1/3}Al_{7/3}Si_{11/3}O_{10} \rightleftarrows Na^+ + 7Al(OH)_4^- + 11H_4SiO_4 \tag{1}$$

$$4NaAlSi_3O_8 + 4CO_2 + 22H_2O \rightleftarrows Al_4(Si_4O_{10})(OH)_8 + 8H_4SiO_4 + 4Na^+ + 4HCO_3^- \tag{2}$$

Further, 40% samples showed Na/Cl ratio more than 1, indicating silicate weathering or anthropogenic influences as a potential source of sodium in groundwater samples (Li et al., 2018), whereas 11.1% samples showed Na/Cl ratio very close to 1 representing halite weathering in the study area.

The plot of $SO_4^{2-}+HCO_3^-$ and $Ca^{2+}+Mg^{2+}$ will be close to equiline (1:1) if the dissolution or weathering of calcite, dolomite and gypsum are dominant processes in an aquifer system. In the present study, it is apparent from Fig. 3(b) that 46.7% of groundwater samples fall above the 1:1 equiline revealing carbonate weathering and 40% samples fall below the equiline due to excess of bicarbonate indicating silicate weathering (Bouderbala, 2017). The groundwater sample points along the 1:1 equiline signify chemical composition of water, in this case, is an outcome of both carbonate as well as silicate dissolution (Tiwari and Singh, 2014); only six samples fall in this chemical composition type. In majority of the samples $Ca^{2+}+Mg^{2+}$ concentrations were higher than the $HCO_3^-$ (Fig. 3(c)) suggesting the excess of $Ca^{2+}+Mg^{2+}$ over $HCO_3^-$ indicating that the carbonate weathering is dominant, which contributes $Ca^{2+}$ and $Mg^{2+}$ to groundwater (Li et al., 2018) and that the surplus of $Ca^{2+}+Mg^{2+}$ in the groundwater samples is balanced by $SO_4^{2-}$ and $Cl^-$ ions (Fig. 3(d)). Some of the samples indicated a deficit of $Ca^{2+}+Mg^{2+}$ in relation to $HCO_3^-$ requires that surplus negative charge of $HCO_3^-$ alkalinity must be balanced by alkali metals ($Na^+$ and $K^+$) (Tiwari and Singh, 2014).

### *4.2. Chloro alkaline indices (CAI)*

Study of ion exchange indices is the easiest way to understand the groundwater composition and its interaction with rocks (Schoeller, 1965). For the present study chloro alkaline indices proposed by Schoeller (1965) were evaluated according to Eqs. (3) and (4)

$$CAI - I = \frac{Cl - (Na + K)}{Cl} \tag{3}$$

$$CAI - II = \frac{Cl - (Na + K)}{SO_4 + HCO_3 + CO_3 + NO_3} \tag{4}$$

Where all the units are expressed in meq/L.

CAI with positive value indicates that $Na^+$ and $K^+$ present in water were exchanged with $Ca^{2+}$ and $Mg^{2+}$ during contact with the aquifer material, representing the reverse ion exchange process whereas negative CAI implies that $Ca^{2+}$ and $Mg^{2+}$ in groundwater were replaced by $K^+$ and $Na^+$ representing ion exchange with the surrounding. If CAI value is 0, it implies no exchange, i.e. state of equilibrium between the chemical constituents present in groundwater and aquifer material. In the present study CAI-I value ranges

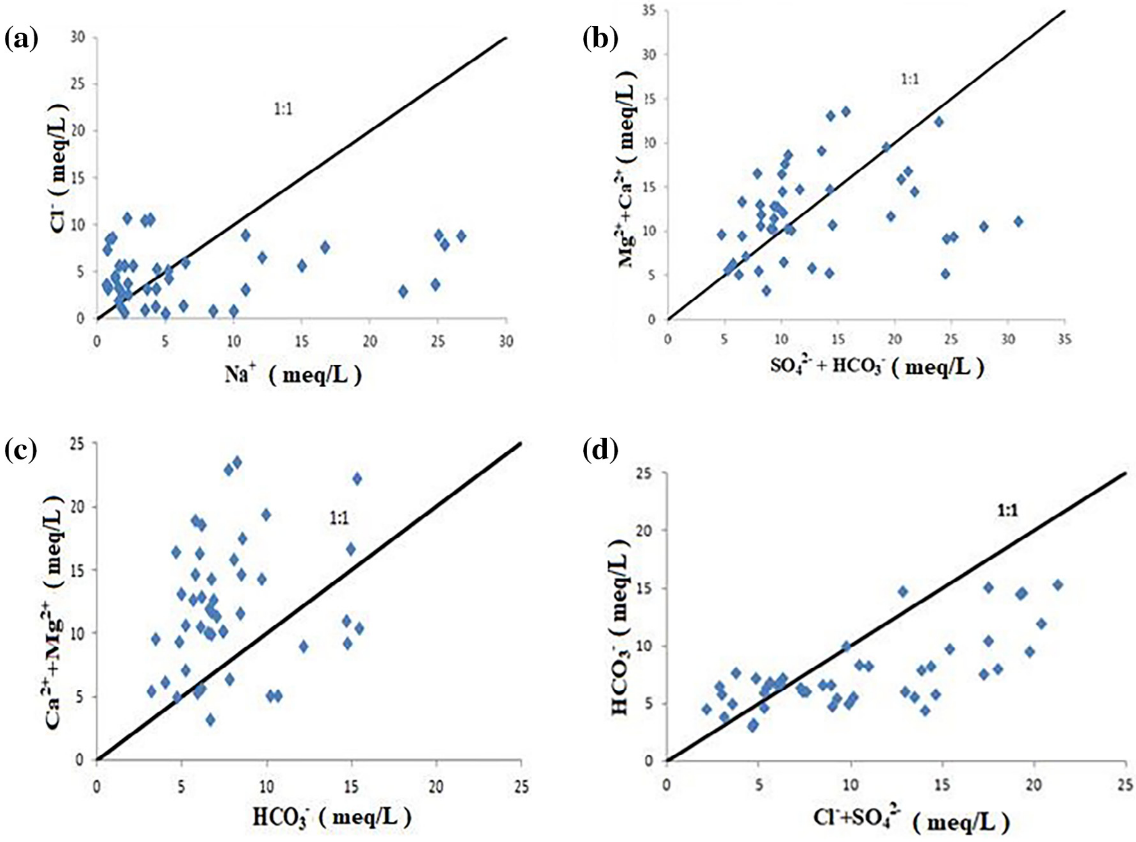

**Fig. 3.** (a). $Na^+$ versus $Cl^-$ plot (b). Relation between $SO4^{2-}$ + $HCO_3^-$ and $Ca^{2+}$ + $Mg^{2+}$, (c) Relation between $HCO_3^-$ and $Ca^{2+}$ + $Mg^{2+}$, (d) Relation between $Cl^-$ + $SO_4^{2-}$ and $HCO_3^-$.

from −12.07 to 0.86, whereas CAI-II value varies from −0.80 to 0.99. CAI-I and CAI-II values calculated for groundwater revealed that 51.11% of samples showed negative CAI, indicating that $Ca^{2+}$ and $Mg^{2+}$ ions in groundwater were replaced by $K^+$ and $Na^+$ ions of surrounding aquifer material. Thus, cation exchange is one of the main processes that can also govern the chemical constituents of the groundwater, whereas 48.89% samples showed positive CAI-I as well as CAI-II values, indicating reverse ion exchange process in the area.

To further supplement the results of weathering processes, different indices approach has been carried out to know the dominant hydrochemical facies of groundwater.

### 4.3. Piper's tri-linear diagram

Piper's tri-linear diagram (Piper, 1944) has been most widely used to understand the hydrochemistry of the area. Piper's diagram is a major key to the identification and classification of rock-water interaction, solution kinetics, geology and sources of contamination in groundwater.

As per Piper's plot (Fig. 4) 71.1% of the samples fall under field I representing $Ca^{2+}$-$Mg^{2+}$-$Cl^-$-$SO_4^{2-}$ type water indicating an excess of alkaline earths than alkalies ($Ca^+$+$Mg^{2+}$>$Na^+$+$K^+$) and excess of stronger acidic anions than weaker acidic anions ($Cl^-$+$SO_4^{2-}$>-$CO_3^-$+$HCO_3^-$) thus indicating permanent hardness (Ravikumar and Somashekar, 2017). Presence of alkaline earth cation facies represents the prevalence of natural weathering over human interventions with few exceptions that may have anthropogenic sources such as leaching of industrial effluent and fertilizers from agricultural fields (Srivastava and Ramanathan, 2018). 15.6% samples belong to field II representing the excess of alkalies over alkaline earths indicating $Na^+$+$K^+$-$Cl^-$+$SO_4^{2-}$ type water indicating halite weathering. 11.1% samples fall under category IV indicating $Ca^{2+}$-$Mg^{2+}$-$SO_4^{2-}$ type water whereas only 2.2% samples belong to $Na^+$-$K^+$–$HCO_3^-$ type water. The diamond plot in Piper's diagram was further classified as per Langguth (1966) in seven fields (A-G). According to this classification, the groundwater samples were distinguished into six fields represented by B, C, D, E, F & G. Field B (17.8% samples) and C (31.1% samples) symbolizes alkaline earths ($Ca^{2+}$+$Mg^{2+}$) with prevailing anions $HCO_3^-$ or $SO_4^{2-}$ or $Cl^-$. Field D (8.9% samples) and E (24.4% samples) represent alkaline earths with dominant $SO_4^{2-}$ or $Cl^-$ anions. Field F (2.2% samples) and G (15.5% samples) indicate alkaline water with prevailing $HCO_3^-$ or $SO_4^{2-}$or $Cl^-$ anions. The dominance of $Ca^{2+}$-$Mg^{2+}$-$Cl^-$ -$SO_4^{2-}$ in the majority of the samples suggest the dissolution of carbonate minerals as well as infiltration of surface salts into groundwater due to irrigational practices in the study area. Sodium dominance in several groundwater samples may be because of acidic silicate mineral dissolution present in alluvium and cation exchange processes on clay particles. The source of bicarbonate in groundwater may be due to agricultural return flow cycle that makes a way for leaching of the carbonate mineral precipitates until it achieves the supersaturation state with calcite and dolomite in the groundwater. It is also noticeable that 40% of groundwater samples fall under mixed water type, where groundwater cannot be considered either as cation or anion dominant type (Herojeet et al., 2017).

### 4.4. Chadha's diagram

A diagram introduced by Chadha (1999) was also evaluated to determine the various hydro-geochemical processes in the region. The plot was prepared by converting data into percentage equivalents (meq%) and denoted as difference among milliequivalent

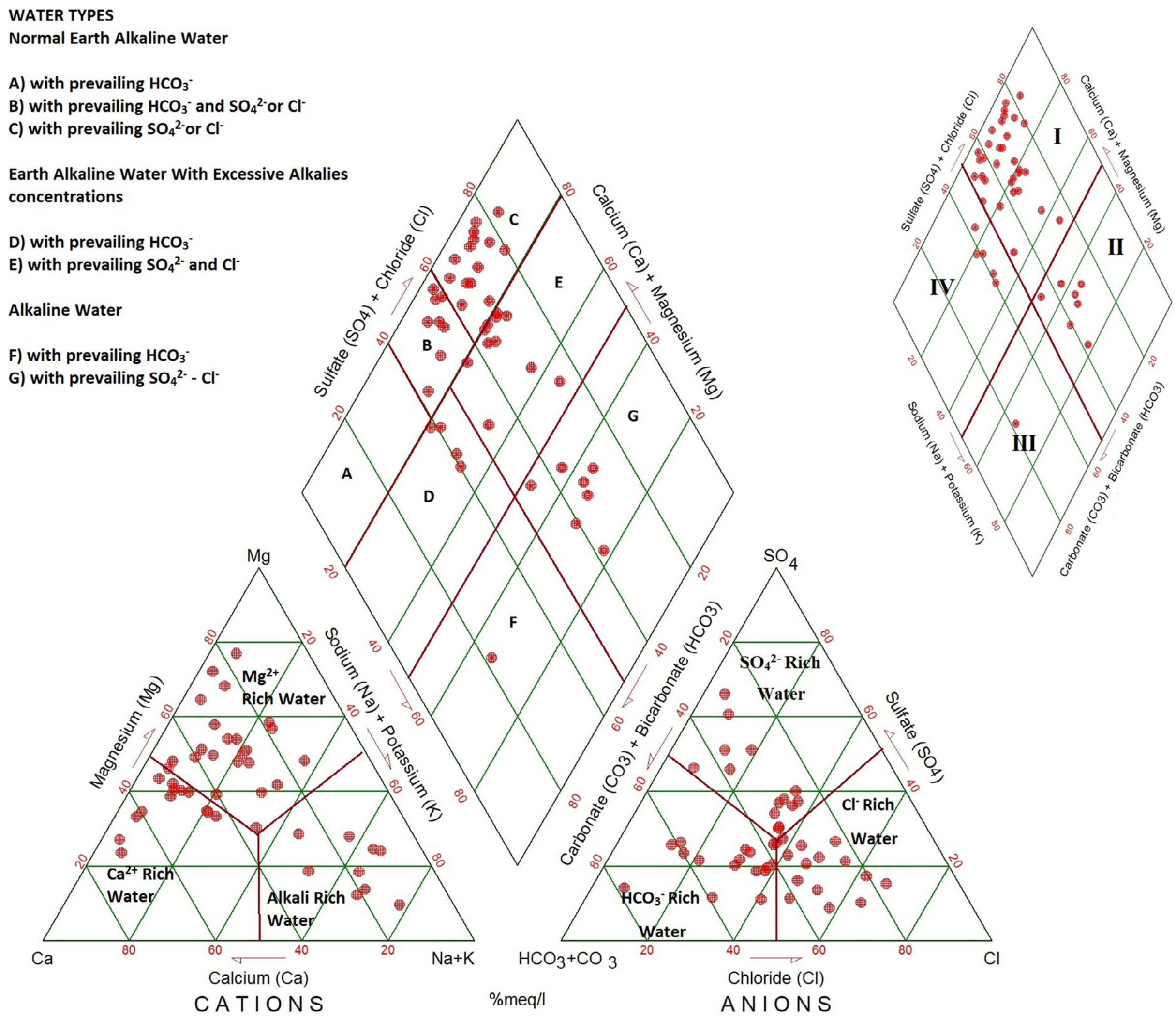

**Fig. 4.** Piper tri-linear plot showing major hydrochemical facies in the groundwater samples (Langguth, 1966).

percentages of alkaline earth metals ($Ca^{2+}$+$Mg^{2+}$) and alkali metals ($Na^{+}$+$K^{+}$) for cations on X-axis and difference among weaker acidic anions ($CO_3^{2-}$+$HCO_3^{-}$) and stronger acidic anions ($Cl^{-}$+$SO_4^{2-}$) on Y axis as shown in Fig. 5. Each quadrant of the plot indicates a specific hydro-geochemical process which further broadly classified as recharge water ($Ca^{2+}$-$Mg^{2+}$–$HCO_3^{-}$ type), reverse ion exchange ($Ca^{2+}$-$Mg^{2+}$-$Cl^{-}$ type), seawater ($Na^{+}$-$Cl^{-}$ type) end member and base ion exchange water ($Na^{+}$–$HCO_3^{-}$). Fig. 5 indicates that most of the groundwater samples exhibits permanent hardness or reverse ion exchange water, meaning that $Ca^{2+}$ + $Mg^{2+}$ are in abundance than $Na^{+}$ + $K^{+}$ ions which may be caused by the release of $Ca^{2+}$ and $Mg^{2+}$ ions from exposed aquifer rock weathering such as carbonate rocks or perhaps reverse base cation exchange processes of alkali earth's metals into solution and consequent $Na^{+}$ adsorption onto the exposed rock mineral surfaces (Bouderbala, 2017). 15.6% samples fall under field 7, indicating sea water end member type i.e. alkalies surpasses alkaline earths and stronger acidic anions surpass weaker acidic anions and usually causes problems of salinity thus making it unfit for domestic as well as irrigation purposes (Chadha, 1999). Some of the samples belong to field 8 indicating an excess of alkalies over alkaline earths and weaker acidic anions surpass stronger acid anions thus signifying this type of waters deposit residual sodium carbonate which creates foaming problems in irrigation. Very few samples fall under Field 5, representing recharge type of water, evolved when water infiltrates into the aquifer from the surface irrigation and carries dissolved $HCO_3^{-}$ and geochemically transportable/mobile $Ca^{2+}$.

The results of Piper and Chadha's plot both revealed that alkali earths and strong acidic anions were abundant in the groundwater samples than the alkalies and weak acidic anions respectively thus indicating permanent hardness and reverse ion exchange.

### 4.5. Factor analysis

The factor analysis for the groundwater quality of only selected parameters ($Cl^{-}$, $SO_4^{2-}$, $NO_3^{-}$ $Ca^{2+}$ $Mg^{2+}$, $HCO_3^{-}$ $Na^{+}$, $K^{+}$ and TH) was carried out using rotated varimax method in Minitab 18 software and the results are shown in Table 2, indicating complex chemical nature of the region. In rotated varimax method total 3 factors were extracted accounting 74.8% of entire data variability representing the good insight of data structure and affirming the results of major controlling processes in the present study.

The rotated varimax factor 1 describes 37.10% of the overall variance and strong positive factor loadings of TH, $Ca^{2+}$, $Cl^{-}$ and $Mg^{2+}$ indicating leaching of salts along with rock-water interface in the aquifer. The prevailing cations in this factor were $Ca^{2+}$, $Mg^{2+}$ that may have originated due to weathering of carbonate and silicate or owing to reverse ion exchange processes (Subramani et al., 2010). The presence of $Ca^{2+}$, $Mg^{2+}$ and $Cl^{-}$ and their high positive factor loadings with TH indicates the

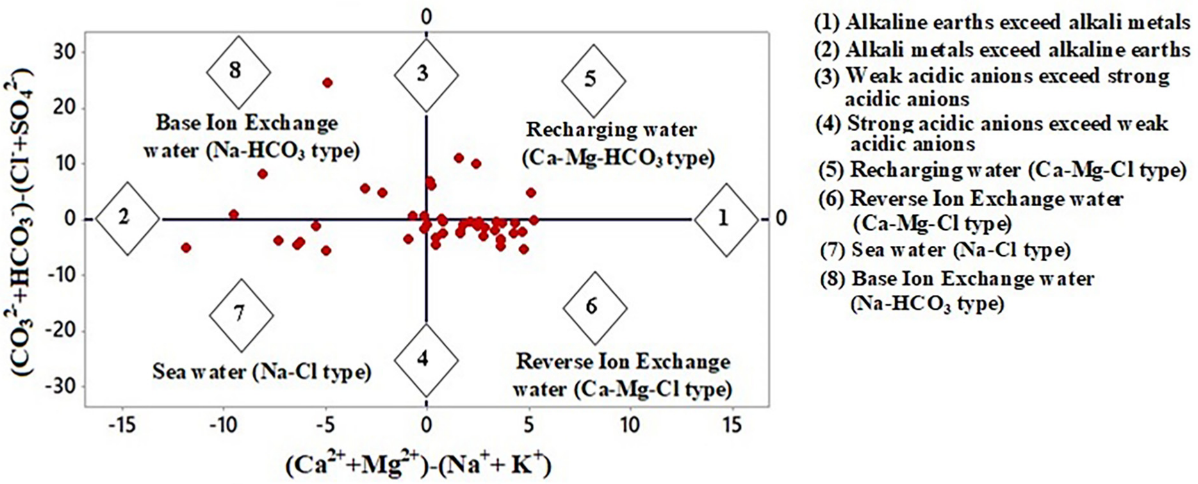

**Fig. 5.** Chadha's plot showing hydrochemical processes involved in groundwater samples.

**Table 2**
Factor analysis for the groundwater quality parameters.

| Variable | Factor 1 | Factor 2 | Factor 3 |
|---|---|---|---|
| Varimax rotated (n = 45) | | | |
| $Cl^-$ | **0.785** | 0.237 | 0.237 |
| $SO_4^{2-}$ | 0.129 | **0.870** | 0.125 |
| $NO_3^-$ | 0.433 | 0.267 | **0.642** |
| $Ca^{2+}$ | **0.830** | −0.094 | 0.043 |
| $Mg^{2+}$ | **0.689** | 0.143 | −0.033 |
| $HCO_3^-$ | 0.193 | **0.900** | 0.067 |
| $Na^+$ | −0.166 | **0.941** | 0.201 |
| $K^+$ | −0.133 | 0.110 | **0.886** |
| TH | **0.849** | −0.047 | −0.068 |
| Eigen value | 3.34 | 2.37 | 1.02 |
| Variance (%) | 37.10 | 26.32 | 11.38 |
| Cumulative (%) | 37.10 | 63.42 | 74.8 |

The values represented in bold indicates positive loadings of the corresponding variables in extracted factors.

contribution of these chemical species to the total hardness of the groundwater.

Rotated varimax factor 2 represents strong positive loadings of $Na^+$, $HCO_3^-$ and $SO_4^{2-}$ and explains 26.32% of total variance. The dominant ion in this factor is $Na^+$ indicating the presence of $Na^+$ in groundwater is due to weathering of sodium containing feldspar (Albite). Higher loading of $HCO_3^-$ and $SO_4^{2-}$ in factor 2 indicates silicate weathering and also represents the recharge processes (Prasanna et al., 2010; Subramani et al., 2010).

Rotated varimax factor 3 describes 11.38% of total sum of variance and strong positive factor loadings for $K^+$ and $NO_3^-$. The presence of both $K^+$ and $NO_3^-$ signifying the impact of anthropogenic activities from agricultural processes. The presence of nitrate in the groundwater indicates seepage of sewage or industrial effluent or intensive application of nitrate fertilizer in agricultural practices.

It can be concluded from the factor analysis that the dominant hydrogeochemical processes are weathering of aquifer material, ion exchange and anthropogenic impacts including agricultural and industrial processes.

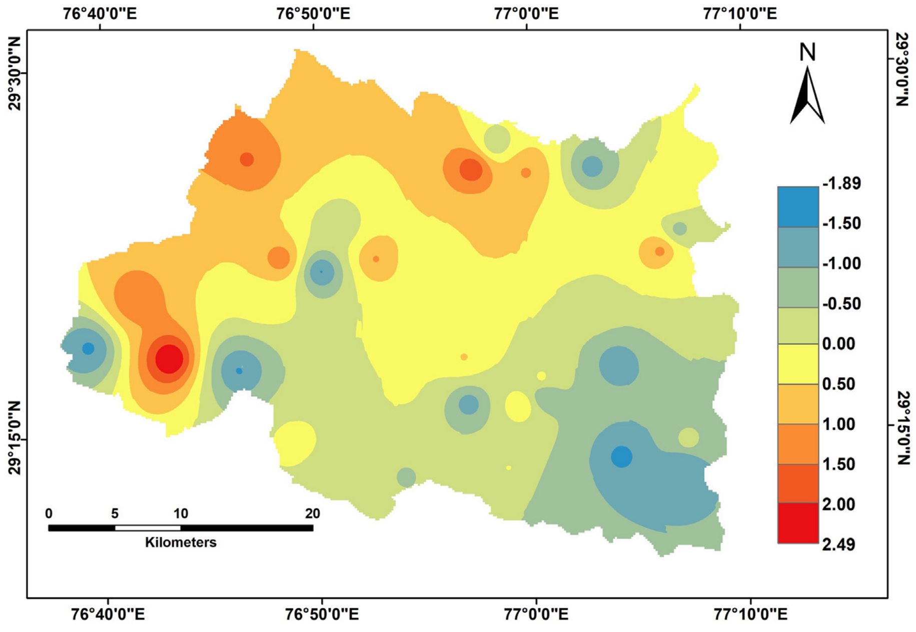

**Fig. 6.** Map showing spatial distribution of factor 1 in groundwater system of Panipat.

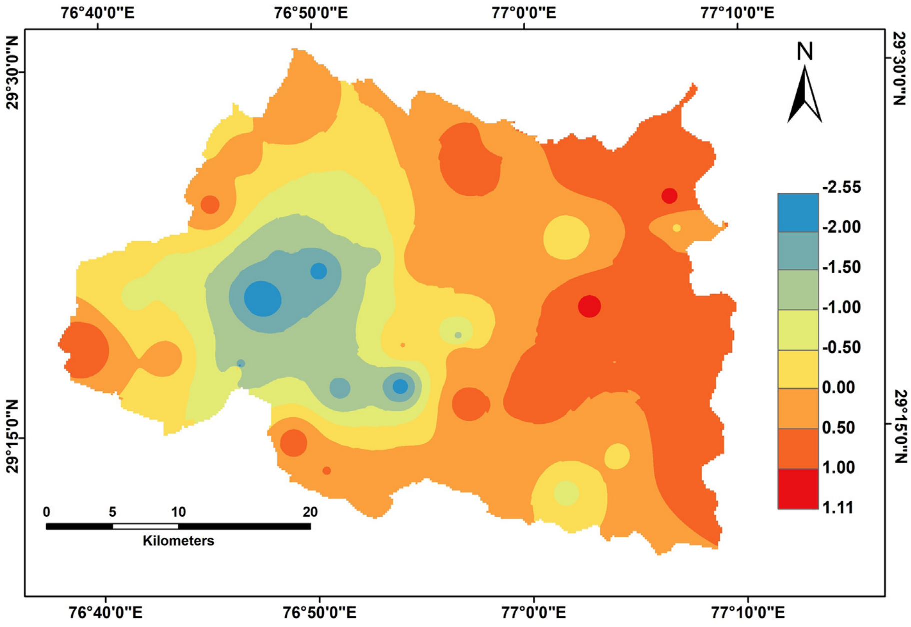

**Fig. 7.** Map showing spatial distribution of factor 2 in groundwater system of Panipat.

### *4.5.1. Spatial variation of factor scores*

For the present study, the factor scores were derived for the estimation of spatial variability of dominant factors in the area. The factor scores used in the study were extracted by multiplying a factor score coefficient matrix with standardized data for each water sample location. The positive factor score zones represent the predominance of that particular factor i.e. hydrogeochemical processes. Inverse Distance Weighting (IDW) technique was employed for the interpolation of factor scores of each sampling location to prepare spatial variability maps. The spatial distribution of factor 1 is shown in Fig. 6 representing dominance of factor 1 scores towards the North-Western region of the study area indicating the prevalence of rock material and water interaction or carbonate and silicate weathering or reverse ion exchange in this zone. The spatial distribution of factor 2 is given in Fig. 7, clearly representing dominance of factor 2 in the north to south stretch towards the eastern side of the study area indicating albite and silicate weathering along with recharge processes as river Yamuna flows throughout the eastern side in the district. A perusal of Fig. 8 clearly depicts that the dominance of factor 3 is towards the south-west region in the study area and that the anthropogenic impacts are not only restricted to the southwestern side of the district but are conspicuous in other parts of the study area in patches.

## 5. Conclusions

The aquifer hydrogeochemistry in Panipat is remarkably influenced by weathering of the aquifer rock material mainly carbonate

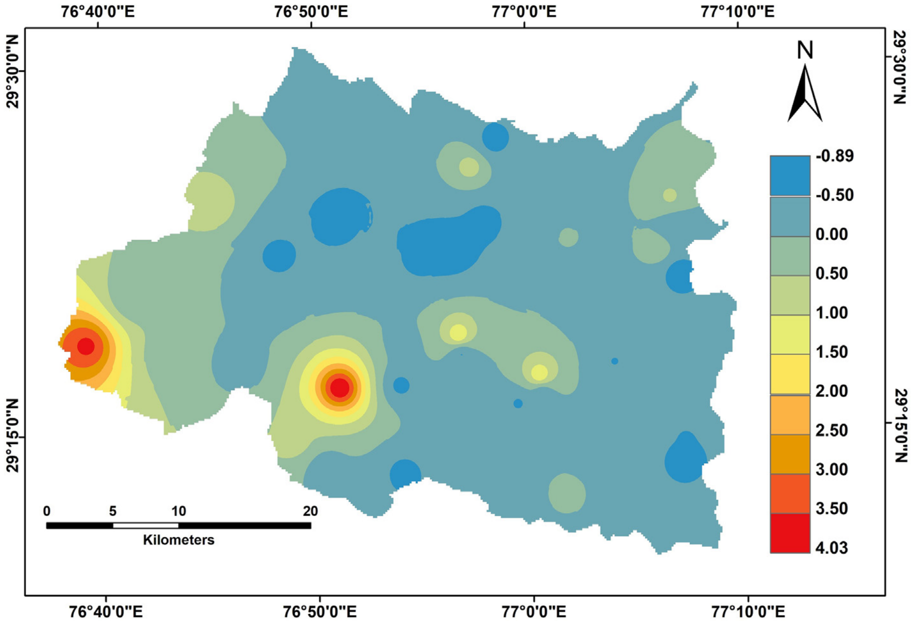

**Fig. 8.** Map showing spatial distribution of factor 3 in groundwater system of Panipat.

and silicate-containing minerals. The inter-ionic interaction graphs indicated carbonate and silicate weathering in most of the groundwater samples. The chloro alkaline indices revealed nearly equal dominance of ion exchange as well as reverse ion exchange processes in the region. Piper's plot and Chadha's plot revealed rock weathering (reverse ion exchange) in most of the groundwater samples indicating $Ca^{2+}$+$Mg^{2+}$-$Cl^{-}$+$SO_4^{2-}$ water type representing permanent hardness in the region. This was further supported by the factor analysis which also suggested that the dominant hydrogeochemical processes in the region were weathering, ion exchange and anthropogenic influences. The anthropogenic influx from agricultural and industrial sources may pose a great threat to groundwater resources in the region. The present investigation demonstrates the major hydrogeochemical and anthropogenic processes responsible for the aquifer chemistry in the region which in turn may help in the groundwater quality management, policy formulation and decision making in the study area.

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