Appraisal of long term groundwater quality of peninsular India using water quality index and fractal dimension

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A review has been made to understand the hydrogeochemical behaviour of groundwater through statistical analysis of long term water quality data (year 2005–2013). Water Quality Index (*WQI*), descriptive statistics, Hurst exponent, fractal dimension and predictability index were estimated for each water parameter. *WQI* results showed that majority of samples fall in moderate category during 2005–2013, but monitoring site four falls under severe category (water unfit for domestic use). Brownian time series behaviour (a true random walk nature) exists between calcium (Ca^{2+}) and electric conductivity (*EC*); magnesium (Mg^{2+}) with *EC*; sodium (Na^+) with *EC*; sulphate (SO_4^{2-}) with *EC*; total dissolved solids (*TDS*) with chloride (Cl^-) during pre- (2005–2013) and post- (2006–2013) monsoon season. These parameters have a closer value of Hurst exponent (*H*) with Brownian time series behaviour condition ($H = 0.5$). The result of times series analysis of water quality data shows a persistent behaviour (a positive autocorrelation) that has played a role between Cl^- and Mg^{2+} , Cl^- and Ca^{2+} , *TDS* and Na^+ , *TDS* and SO_4^{2-} , *TDS* and Ca^{2+} in pre- and post-monsoon time series because of the higher value of *H* (>1). Whereas an anti-persistent behaviour (or negative autocorrelation) was found between Cl^- and *EC*, *TDS* and *EC* during pre- and post-monsoon due to low value of *H*. The work outline shows that the groundwater of few areas needs treatment before direct consumption, and it also needs to be protected from contamination.

Keywords. Fractal dimension; Hurst exponent; predictability index; water quality index.

1. Introduction

In recent decade it was found that many regions of the world's groundwater and surface water is getting polluted due to industrialization, unprecedented

population growth, deforestation and extensive agriculture (Singh *et al.* 2010, 2013a, b; Oişte 2014; Rawat and Tripathi 2015; Nemčić-Jurec *et al.* 2017) and land transformation (Amin *et al.* 2014) on the quality of drinking water resources (Thakur *et al.*

2015). The World Health Organization (WHO) has given standard criteria for drinking water. Water quality of watersheds is studied using hydro-chemical data that merge with multiple linear regression (Chenini *et al.* 2008; Mousavi *et al.* 2008; Chenini and Khemiri 2009) to know the constituent concentrations. Constituent concentrations can be used by water quality managers for the assessment of current water quality states to water quality standards. Examination of physical properties of groundwater that act as surrogates for constituents of interest also helps in the collection of water quality samples (Vassilis *et al.* 2001; Carlson and Ecker 2002; Joarder *et al.* 2008; Psargaonkar *et al.* 2008; Korashey 2009).

The simple statistical analysis of water quality data of groundwater collected from hand pumps at Moradabad, India, help the drinking water quality status. The conductivity of water was high (Kumar and Sinha 2010). Common people are not aware about these standards. It is also difficult for the authority to make any decision based on these different parameters; to understand the combined effects of those elements present in the water through numerical indices such as Water Quality Index (*WQI*), in terms of numeric (Singh *et al.* 2015). Most water quality indices rely on normalizing or standardizing data, parameter by parameter, according to expected concentrations and some interpretation of 'good' *vs.* 'bad' concentrations. Parameters are often then weighed according to their perceived importance to overall water quality and the index is calculated as the weighted average of all observations of interest (Pesce and Wunderlin 2000; Sargaonkar and Deshpande 2003; Stambuk-Giljanovik 2003; Liou *et al.* 2004; Tsegaye *et al.* 2006). Normally, the composite form has a qualitative characteristic. Many researchers have used numerical indices such as water quality index (*WQI*; Singh *et al.* 2015), synthetic pollution index (*SPI*; Gautam *et al.* 2015), normalized difference dispersal index (NDDI; Rawat *et al.* 2017a,b), and normalized difference index (NDI; Singh *et al.* 2013a,b) to categorize water for different levels of pollution. The *WQI* is most widely used for classification of water with respect to pollution category. Rawat *et al.* (2017a) used NDDI to map groundwater quality of Dwarka sub-city at Delhi (National Capital of India). Singh *et al.* (2013a,b) used NDI with geochemical indicators and GIS to map the fluoride contamination of groundwater in northern India. Singh *et al.* (2015) modelled groundwater quality over a humid subtropical

region using numerical indices, earth observation datasets, and X-ray diffraction technique: A case study of Allahabad district, India.

The concept of water quality to categorize water according to its degree of purity or pollution dated back to year 1848 (Vidyalakshmi *et al.* 2013; Singh *et al.* 2015) and has been recognized for its importance to public health in the United Kingdom (Snow 1856). *WQI* methodology has been developed to provide a numeric value that represents the overall water quality, based on several water quality parameters (Avvannavar and Shrihari 2008; Vasanthavigar *et al.* 2010; Parmar and Bhardwaj 2013; Singh *et al.* 2015) and can be used to provide the overall summaries of water quality on a scientific basis (Kaurish and Younos 2007). Many researchers have discussed the importance and applicability of numerical index such as *WQI* for water characterization (Couillard and Lefebvre 1985; House and Newsome 1989; Smith 1989; Swamee and Tyagi 2000; Bordalo *et al.* 2001; Sánchez *et al.* 2007; Singh *et al.* 2015). For instance, *WQI* is a single numeric value that explained the complex information of any water body mainly about water quality. Parmer and Bhardwaj (2013) have applied *WQI* and fractal dimension approach to study the water of Harike lake on the confluence of Beas and Sutlej rivers of Punjab (India). Singh *et al.* (2016) applied the *WQI* to study the status of Bhopal lake water.

The objective of this study was to evaluate the long term (2006–2013) groundwater quality using the *WQI*, with reference to the standard recommended by WHO 2006 and to understand the behaviour of ions through fractal dimension analysis and also to explore the relationship using regression equations. Further, in the work, statistical analysis, regression equations, Hurst exponent (*H*), fractal dimension (*D*), predictability index (*PI*) and *WQI* have been applied on groundwater quality data for better understanding regarding the hydrogeochemical processes that control the hydrogeochemistry of groundwater of the studied region.

2. Study area

Kanchipuram district of Tamil Nadu (India) state, lies between 11°00'–12°00' North latitudes and 77°28'–78°50' East longitudes (northeast coast of Tamil Nadu) and on the banks of the Vegavathi River, a tributary of the Palar River (figure 1). The study area has an average elevation of 83.2 m

Figure 1. Study area land use/land cover map with 44 sample monitoring points (*).

above mean sea level, hence flat, and slopes towards the south and east and is bound by Bay of Bengal in the east. Three types of soil (i) clay with some loam, (ii) clay, and (iii) sand are reported in the area (table 1). Agriculture is the main occupation in the region with 47% of the population engaged in it. Paddy is a major crop in the region, while other crops are groundnut, sugarcane, cereals and millets and pulses (table 1). The total forest area in the district is 426.57 km² and it is spread in interior regions and around the district. The pre-monsoon rainfall is almost uniform throughout the district. Northeast and southwest monsoon are responsible for rain with 54% and 36% contribution each to the total annual rainfall. During normal monsoon, the district receives an average annual rainfall of 1213.3 mm (table 1).

3. Hydrogeology

The district is underlain by both sedimentary and fissured formations. The aquifer system of areas are generally constituted by unconsolidated and semi-consolidated formations and weathered, fissured and fractured crystalline rocks.

3.1 Semi-consolidated, unconsolidated alluvium and fissured formations

Gondwana sandstones and shales and tertiary mottled clays and sandstones represent the porous, semi-consolidated sediments. Groundwater occurs under water table conditions to confined conditions in inter-granular spaces of sandstones, sands and in the bedding planes and thin fractures of shales, depth of water table ranges from 5 to 10 m bgl. Unconsolidated formations (alluvium) occur mainly along the banks of Palar and Cheyyar rivers and the sand layers form the potential aquifer. The area lies between Walajabad and Kancheepuram and has small diameter dug wells tap the alluvium with depths ranging between 6 and 12 m bgl. Some areas are covered by the laterites, where dug wells depth varies from 4 to 6 m bgl. Along the coast, windblown sand acts as aquifer zones and groundwater extraction is by means of shallow dug wells with radial arms. Principally joints, fissured fractures and their interconnections control the movement of groundwater in fissured crystalline (Balakrishnan 2007).

4. Materials and method

4.1 Laboratory analysis

The groundwater quality data was acquired from Chennai Water Metro Board/Central Ground Water Board (CGWB) of pre- and post-monsoon season for the period 2005–2013. Out of 44 sampling wells, most of the wells are located near the agricultural fields, while a few are located in the village and town. The collected samples were analyzed by the unit of CGWB, according to APHA guidelines (1996) in the laboratory to measure the cations: Calcium (Ca²⁺), Magnesium (Mg²⁺), Sodium (Na⁺), Potassium (K⁺), anions: Bicarbonate (HCO₃⁻), Nitrate (NO₃⁻), Chloride (Cl⁻), Fluoride (F⁻), Sulphate (SO₄²⁻), Carbon trioxide (Carbonate, CO₃²⁻), Total dissolved solids (TDS) and physical parameters as hydrogen ion concentration (pH) and electrical conductivity (EC) in the samples (figure 1).

4.2 Water quality index

The *WQI* was calculated using the standards of drinking water quality recommended by the WHO (2006). Further, the weighted arithmetic index method (Brown *et al.* 1970) was used for the

Table 1. General information about study area (source: www.kanchi.tn.nic.in).

Total area	4393.37 km ²
Net sown area	1364.89 km ²
Net irrigation area	1236.28 km ²
Forest area	426.57 km ²
Poromboke area	1553.47 km ²
Town area	82.57 km ²
Number of Panchayat villages	648
Summer temperature	21.1–36.6°C
Winter temperature	19.8–28.7°C
Rainfall	1133.0 mm (actual), 1213.3 mm (normal)
Major crops	Rice (145966 ha), Sugarcane (7586 ha), Groundnut (28766 ha), Gingelly (912 ha), Pulses (2966 ha), Cotton (53 ha), Millets and Cereals (1217 ha)
Soil types	Read loam (Kanchipuram, Uthiramerur Blocks), lateritic soil (Pleatus in the district), black soil (spread in all blocks), sandy coastal alluvium (Thiruporur and St. Thomas Mount) and red sandy soil (Kancheepuram and urban blocks)

calculation of *WQI* of the surface water. Quality rating or sub-index (Q_n) was calculated using the following expression (1–4).

$$Q_n = 100 \times [(V_n - V_i) / (V_s - V_i)] \quad (1)$$

Q_n is quality rating for the n th water quality parameter, V_n is actual value of n th parameter, V_i is ideal value of this parameter (according WHO-2006), and V_s is standard permissible value of the n th parameter (WHO 2006). (Consider $V_i = 0$ for all except pH where $V_i = 7$ for pH.)

Unit weight was calculated by a value inversely proportional to the recommended standard value V_s of the corresponding parameter.

$$W_n = \frac{K}{V_s} \quad (2)$$

and

$$K = \left[1 / \sum_{n=1}^n (1/V_s) \right]$$

W_n is unit weight for the n th parameter, K is constant of proportionality, and V_s is standard value for the n th parameter.

For computing the *WQI*, the SI (sub-index) is first to determine for each chemical parameter, which is then used to determine the (*WQI*) as per the following equation:

$$SI_n = (Q_n)^{W_n} \quad (3)$$

Overall *WQI* is calculated taking geometric mean of all sub-indices.

$$\begin{aligned} WQI &= \text{antilog}_{10} [\log_{10} (SI)_n] \\ &= \text{antilog}_{10} \left[\sum_{n=1}^i W_n \log_{10} Q_n \right] \end{aligned} \quad (4)$$

WQI classes are classified on the basis of Brown *et al.* (1972), Chatterji and Raziuddin (2002) and Singh *et al.* (2015). According to Brown *et al.* (1972), Chatterji and Raziuddin (2002) *WQI* values are rated as excellent ($WQI < 25$), good ($26 < WQI < 50$), poor ($51 < WQI < 75$), very poor ($76 < WQI < 100$) and unfit for human consumption ($WQI > 100$) (table 2b).

4.3 Statistical analysis

The statistical data analysis involved in mean, median, mode, standard deviation, kurtosis, skewness, coefficient of variation, regression lines, correlation coefficient, Hurst exponent, fractal dimension and predictability index were calculated for each water quality parameter to understand the variability. The statistical measures, namely, mean explains the average value, median gives the middle values of an ordered sequence or positional average and mode gives the value which occurs the maximum number of times that has the maximum frequency. Standard deviation explains the measure of spread or variability of the sample. The degree of flatness or peakedness in the region about the mode of a frequency curve is defined

Table 2. (a) Constant of proportionality (K) and unit weight (W_n) for groundwater parameter. (b) Rating and category chart of WQI.

Parameter	Standard permissible value of parameter	Unit weight (W_n) $W_n = K/V_n$
(a)		
pH	8.5	0.556
EC	1400 (dS/m)	0.003
TDS	1000 (mg/l)	0.005
Na	200 (mg/l)	0.024
Ca	75 (mg/l)	0.063
Mg	50 (mg/l)	0.094
K	55 (mg/l)	0.086
Cl ⁻	250 (mg/l)	0.019
HCO ₃ ⁻	1000 (mg/l)	0.005
NO ₃ ⁻	50 (mg/l)	0.094
SO ₄ ²⁻	400 (mg/l)	0.012
CO ₃ ²⁻	120 (mg/l)	0.039
	$K = \sum V_n = 4.72$	$\sum W_n = 1$
(b)		
Sl. no.	WQI	Water quality status
1	0–25	Suitable (excellent)
2	26–50	Slightly polluted (very good)
3	51–75	Moderately polluted (good)
4	76–100	Highly polluted (poor)
5	>100	Unfit (very poor)

by Kurtosis. Skewness describes the symmetry of data. Coefficient of variation (CV) gives the relative measure of the sample (Parmer and Bhardwaj 2013).

4.4 Regression analysis (RA)

Regression analysis is a technique of mathematically sorting (removing) out those variables which does not have any strong statistical relationship between dependent variables and independent variables. Regression line of Y (dependent variable) on X (independent variable) is defined as:

$$Y = mX + C, \quad (5)$$

where m is the slope and C is the intercept (the point where the line crosses the y-axis).

Equation (5) represents a linear regression equation of linear line, linear relationship between X and Y . The regression coefficient has been calculated using equation (6).

$$m = r \times SD_y / SD_x \quad (6)$$

m is a regression coefficient, r is correlation coefficient, SD_y standard deviation of Y series and SD_x is standard deviation of X series.

This shows that r is the slope of the regression line of the standardized data points (and that this line passes through the origin). It is sometimes useful to calculate r_{xy} from the data independently using this equation (7):

$$r_{xy} = \frac{E(XY) - E(X)E(Y)}{\sqrt{(E(X^2) - E(X)^2)(E(Y^2) - E(Y)^2)}} \quad (7)$$

where $r_{x,y}$ is correlation coefficient, $E(XY)$, $E(Y)$, $E(X)$ are the expected value of variables XY , Y and X , respectively.

4.5 Fractal dimensional analysis (FD)

The assumption of groundwater quality parameters of a time series can be modeled as a stationary stochastic. We adopted the Rangarajan and Sant (2004) method of mathematical formulation of FD. Stationary stochastic process is considered in discrete time $\{\xi_k\}$, with $\langle \xi_k \rangle = 0$ and $\{\xi_k^2\} = \sigma^2$ where $\langle \rangle$ denotes ensemble average. If the autocorrelation

function $C(n) = \langle \xi_k \xi_{k+n} \rangle$ scales with the lag n as:

$$C(n) \sim n^{-\beta}. \quad (8)$$

For large n , where $0 < \beta < 1$, then $\{\xi_k\}$ is called a long memory process. The reason for the latter term is that $C(n)$ decays so slowly that $\sum_{n=1}^N C(n)$ diverges as $N \rightarrow \infty$. Most often, long time series exhibits this long memory property. A common method to assess the correlation structure of $\{\xi_k\}$ is to convert the stationary process to a random walk by using partial sums,

$$\begin{aligned} R_1 &= \xi_k, \\ R_2 &= \xi_1 + \xi_2, \\ &\dots\dots\dots \\ R_n &= \xi_1 + \xi_2 + \dots + \xi_n, \end{aligned}$$

where R_n is the position of the walker at time n . The mean range of the random walk trajectory as a function of time bears specific relations with the scaling relation (equation 8). The mean square displacement as a measure of the random walk is considered for analytical evaluation, which is defined as

$$\begin{aligned} \langle R_n^2 \rangle &= \sum_{i=1}^n \langle R_i^2 \rangle + 2 \sum_{s=1}^{n-1} (n-s) C(s) \\ &= n \sigma^2 + 2n \sum_{s=1}^{n-1} C(s) - 2 \sum_{s=1}^{n-1} s C(s). \end{aligned}$$

Let $C(s)$ obey the scaling law in equation (8). The sum in the above equation is estimated as:

$$\sum_{s=1}^{n-1} C(s) \sim \sum_{s=1}^n s^{-\beta} \sim \int_1^n s^{-\beta} \sim n^{1-\beta}$$

and

$$\sum_{s=1}^{n-1} s C(s) \sim \sum_{s=1}^n s^{1-\beta} \sim \int_1^n s^{1-\beta} \approx n^{1-\beta}.$$

For $0 < \beta < 1$, this means

$$\langle R_n^2 \rangle \sim n^{2-\beta}.$$

for large n .

Conventionally, the mean square displacement is characterized by Hurst exponent (H) as equation (9):

$$\langle R_n^2 \rangle \sim n^{2H} \text{ (Power law of decay)} \quad (9)$$

where $H = (2 - \beta)/2$.

4.6 Hurst exponent (H)

Hurst exponent (H) reveals the index of dependence. It computes the relative tendency of a time series either to regress strongly to the mean or to bunching in a path. The value of H ranges between 0 and 1. A value of 0.5 indicates a Brownian time series (a true random walk). In a Brownian time series, there is no strong correlation between any element and a future element. A Hurst exponent value, $0.5 < H < 1$ shows a positive autocorrelation (a *persistent behaviour*). If there is an increase from time step t_{i-1} to t_i , there will probably be an increase from t_i to t_{i+1} . The same is true of decline, where a decline will tend to follow a decline. H value $0 < H < 0.5$, will exist for a time series with negative autocorrelation (or *anti-persistent behaviour*). Here, raise will tend to be followed by a decline or decline will be followed by raise. This performance is sometimes called *mean reversion* (Rangarajan and Sant 2004). H can be computed using the following mathematical expression in equation (10)

$$H = \left| \frac{m-1}{2} \right|. \quad (10)$$

4.7 Fractal dimension (D)

Fractal dimension (D) is a statistical test that provides an indication of how completely a fractal comes into view to fill space, as one zooms to greater and greater scales (Rangarajan and Sant 2004). H is related to D of the time series curve by the following expression by equation (11)

$$D = 2 - H. \quad (11)$$

If the D for the time series is 1.5, there is no correlation between variables of two successive time intervals. Therefore, no trend in variables can be distinguished from the time series and therefore the process is unpredictable. But, as the D decreases to 1, the process becomes more and more predictable as it exhibits *persistence*. That is, the future trend is more and more likely to follow an established trend (Hsui et al. 1993). D increases from 1.5 to 2, the process exhibits *anti-persistence*. That is, a

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Figure 2. (a) Yearly (2005–2013) value of pre-monsoon pH concentration. (b) Yearly (2006–2013) value of post-monsoon pH concentration. (c) Yearly (2005–2013) value of pre-monsoon EC concentration. (d) Yearly (2006–2013) value of post-monsoon EC concentration. (e) Yearly (2005–2013) value of pre-monsoon Ca concentration. (f) Yearly (2006–2013) value of post-monsoon Ca concentration. (g) Yearly (2005–2013) value of pre-monsoon Mg concentration. (h) Yearly (2006–2013) value of post-monsoon Mg concentration. (i) Yearly (2005–2013) value of pre-monsoon Na concentration. (j) Yearly (2006–2013) value of post-monsoon Na concentration. (k) Yearly (2005–2013) value of pre-monsoon K concentration. (l) Yearly (2006–2013) value of post-monsoon K concentration. (m) Yearly (2005–2013) value of pre-monsoon Cl concentration. (n) Yearly (2006–2013) value of post-monsoon Cl concentration. (o) Yearly (2005–2013) value of pre-monsoon SO_4^{2-} concentration. (p) Yearly (2006–2013) value of post-monsoon SO_4^{2-} concentration. (q) Yearly (2005–2013) value of pre-monsoon CO_3^{2-} concentration. (r) Yearly (2006–2013) value of post-monsoon CO_3^{2-} concentration. (s) Yearly (2005–2013) value of pre-monsoon HCO_3^- concentration. (t) Yearly (2006–2013) value of post-monsoon HCO_3^- concentration. (u) Yearly (2005–2013) value of pre-monsoon NO_3^- concentration. (v) Yearly (2006–2013) value of post-monsoon NO_3^- concentration. (w) Yearly (2005–2013) value of pre-monsoon TDS concentration. (x) Yearly (2006–2013) value of post-monsoon TDS concentration.

decrease in correlation of the process is more likely to lead to an increase in the future. Hence, the predictability again increases. We obtain D of the time series (2006–2013 (pre-monsoon) and 2006–2013 (post-monsoon)) corresponding to 12 water quality parameters for a fixed 44 locations in the study area.

4.8 Predictability index (PI)

Predictability index (PI) explains the behaviour of the time series (Rangarajan 1997). The predictability increases in both the cases as when fractal dimension becomes less than 1.5 persistence

behaviour) and greater than 1.5 (anti-persistence behaviour). If one of these indices (H , D and PI) comes close to 0, then the corresponding process towards the Brownian motion (unpredictable). Equation is the expression of PI .

$$PI = 2 |D - 1.5|. \quad (12)$$

5. Results and discussion

5.1 Hydrogeochemistry

Knowledge of groundwater quality of any area is useful in order to achieve the goal of sustainability.

Data from 44 wells were used to study the ground-water chemistry. The major cation, anions and physical water quality parameters are illustrated in figure 2(a–z).

The physicochemical parameters and total cation/anion concentrations of groundwater (GW) at the study area for pre-monsoon for the period 2005–2013 are shown in table 3. EC varied from 180 to 12,240 dS/m with a mean of 1322.90 dS/m. The range, mean and *SD* of pH are 6.80–8.6, 8.37 and 3.20. The mean cation levels in GW followed a descending order as: $\text{Na}^+ > \text{Ca}^{2+} > \text{Mg}^{2+} > \text{K}^+$, 140.54, 64.31, 50.26 and 18.46 mg/l, respectively. Similarly, in case of anions, the mean levels in GW followed a descending order as: $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{CO}_3^{2-} > \text{NO}_3^- > \text{F}^-$, 259.78, 236.10, 92.55, 24.46 8.42 and 0.43 mg/l, respectively. Mean concentration value of pH, EC, Ca^{2+} , Na^+ , K^+ , Cl^- , SO_4^{2-} , CO_3^{2-} , HCO_3^- , NO_3^- and F^- are below the maximum acceptable limits (MAC)/WHO values during pre-monsoon years (2005–2013). The mean concentration value of Mg^{2+} (50.26 mg/l) in pre-monsoon is higher than the MAC/WHO of 50 mg/l (figure 2a).

The mean levels of all the parameters used in this study during post-monsoon years (2006–2013) can be seen in table 3 together with their respective MAC/WHO values taken from the WHO-2006. The results of the descriptive statistics test revealed that there were no statistically significant differences between the mean levels of the parameter values between June (pre-monsoon) and January (post-monsoon). The mean value of K of post-monsoon shows slight increase as 0.93 mg/l compared to pre-monsoon value of K (18.46 mg/l). The mean cation levels in GW followed a descending order as: Na^+ (125.56 mg/l) $>$ Ca^{2+} (62.74 mg/l) $>$ Mg^{2+} (47.93 mg/l) $>$ K^+ (19.39 mg/l). In the same manner for anions, the mean levels in GW during post-monsoon years (2006–2013) followed a descending order as: $\text{HCO}_3^- > \text{Cl}^- > \text{SO}_4^{2-} > \text{CO}_3^{2-} > \text{NO}_3^- > \text{F}^-$, 244.94, 223.54, 76.04, 28.70, 7.15 and 0.39 mg/l, respectively (figure 2b). The mean levels of pH ranged between 8.37 ± 0.40 at pre-monsoon and 8.20 ± 0.43 at post-monsoon (table 3), reflecting acidic waters.

5.2 WQI interpretation

WQI computed values are given in table 4(a–b) and for better visualization, these values are illustrated

Table 3. Yearly statistical analyses of pre-monsoon (2005–2013) and post-monsoon (2006–2013) water parameters.

Sl. no.	Parameters	Pre-monsoon (2005–2013)							Post-monsoon (2006–2013)						
		Mean	Median	Mode	SD	Kurtosis	Sk	Min	Max	CV	Mean	Median	Mode	SD	Kurtosis
1	pH	8.37	8.20	8.20	3.95	383.51	19.49	6.80	8.6	0.47	8.20	8.20	8.20	0.43	−0.19
2	EC	1322.90	1070.00	630.00	1077.26	39.74	4.85	180	12240	0.81	1244.08	1000.00	570.0	864.4	3.82
3	Ca^{2+}	64.31	52.00	32.00	51.22	13.12	3.09	6	392	0.80	62.74	48.00	24.00	53.56	8.73
4	Mg^{2+}	50.26	35.00	29.00	70.61	114.90	9.43	4	1021	1.40	47.93	35.00	32.00	41.70	8.63
5	Na^+	140.54	115.00	46.00	125.89	26.18	3.56	1	1380	0.90	125.56	97.00	69.00	95.63	3.64
6	K^+	18.46	7.00	2.00	28.42	27.69	4.17	0.10	293	1.54	19.39	7.00	4.00	39.62	64.14
7	Cl^-	236.10	149.00	50.00	328.05	76.41	7.28	14	4219	1.39	223.54	135.00	53.00	243.5	6.82
8	SO_4^{2-}	92.55	57.00	48.00	154.96	32.69	5.45	1	1260	1.67	76.04	49.50	96.00	114.3	44.75
9	CO_3^{2-}	24.46	18.18	12.00	19.16	8.20	2.37	0.56	138	0.78	28.70	25.80	24.00	19.20	1.96
10	HCO_3^-	259.78	232.19	244.00	134.07	6.53	1.61	43	1213.54	0.52	244.94	226.00	268.0	122.0	−0.12
11	TDS	782.90	648.00	304.00	653.39	44.95	5.32	113	7341	0.83	725.24	593.00	380.0	484.4	4.18
12	NO_3^-	8.42	6.00	4.00	6.91	2.58	1.50	0.00	40	0.82	7.15	5.00	3.00	7.40	5.91
															2.22

SD = Standard deviation, Sk = skewness, Min = minimum, Max = maximum, CV = coefficient of variation.

Table 4(a). Yearly (2005–2013) value of pre-monsoon water quality index.

Sl. no.	WQI ₂₀₀₅	WQI ₂₀₀₆	WQI ₂₀₀₇	WQI ₂₀₀₈	WQI ₂₀₀₉	WQI ₂₀₁₀	WQI ₂₀₁₁	WQI ₂₀₁₂	WQI ₂₀₁₃
1	8.97	40.76	6.19	26.58	48.69	12.04	16.53	21.37	17.36
2	21.80	51.72	23.53	22.40	15.16	31.39	54.64	44.19	43.97
3	8.13	73.22	26.72	28.37	3.65	15.48	7.38	21.76	7.14
4	23.53	64.79	78.88	34.38	114.57	16.37	74.83	53.09	66.56
5	82.23	43.37	22.59	27.50	40.64	7.02	16.93	47.78	17.94
6	23.32	39.05	10.97	16.71	46.85	15.40	24.63	26.43	22.97
7	26.39	50.91	23.08	23.47	14.05	17.55	24.36	48.92	25.14
8	23.06	49.34	38.30	14.94	11.00	23.01	21.20	22.50	23.64
9	14.96	13.98	16.58	22.35	49.80	14.04	21.17	19.88	17.59
10	5.00	14.83	10.56	24.00	20.57	15.97	8.38	8.17	8.09
11	18.26	39.37	27.24	28.84	17.68	30.70	26.30	22.45	31.29
12	31.66	47.87	39.83	21.64	13.63	13.60	29.29	18.60	34.01
13	20.67	16.55	6.57	30.25	33.23	11.03	6.31	17.80	11.38
14	12.20	39.24	10.85	11.41	53.55	16.77	11.50	12.90	21.05
15	7.72	22.27	13.77	14.93	47.53	8.92	18.91	16.40	20.64
16	12.39	26.94	13.57	23.20	48.83	15.53	22.79	16.54	24.17
17	10.63	38.93	30.02	32.39	75.55	37.06	34.16	26.40	28.75
18	19.60	14.52	12.52	20.36	5.77	28.23	6.93	11.66	28.04
19	13.85	27.38	14.10	11.92	5.67	59.31	6.83	26.42	10.96
20	18.48	26.27	28.35	7.57	44.30	17.31	14.27	21.72	21.72
21	16.68	20.83	29.63	3.86	67.29	26.54	22.92	30.01	26.96
22	19.60	39.81	26.48	86.79	38.05	4.29	20.74	11.74	18.33
23	9.38	28.89	49.45	68.70	87.15	12.49	22.30	41.48	39.77
24	9.88	35.13	13.16	14.55	50.86	24.91	7.61	18.16	22.30
25	19.31	58.04	27.72	47.81	20.25	53.54	32.80	19.90	33.40
26	22.22	35.47	16.63	11.36	33.01	78.34	21.51	29.05	44.04
27	31.90	32.62	20.12	50.24	46.75	23.38	19.30	24.68	28.16
28	11.33	23.40	40.56	37.37	72.36	21.84	46.75	40.03	19.75
29	12.01	50.95	29.16	45.04	53.48	13.75	31.25	26.48	38.19
30	26.05	30.83	56.76	19.63	48.90	12.23	18.09	20.69	24.12
31	26.05	45.26	15.74	16.14	47.81	50.27	2.25	13.13	18.54
32	7.32	15.61	35.39	10.27	32.26	18.18	27.52	38.01	28.05
33	19.86	23.31	27.95	31.18	68.68	8.49	29.24	35.48	31.39
34	32.00	91.61	108.58	49.67	98.17	19.54	10.41	42.24	55.64
35	18.10	52.17	57.75	13.64	62.99	31.63	18.11	35.25	86.29
36	15.35	46.83	24.33	15.31	55.96	41.02	20.08	26.25	18.13
37	28.93	59.56	17.32	14.35	49.85	33.43	7.36	21.36	28.19
38	33.77	42.47	9.99	21.20	54.31	19.44	20.28	22.86	22.83
39	14.13	29.15	8.10	18.32	16.21	17.76	12.76	18.40	33.61
40	16.74	23.67	17.73	12.33	23.09	28.67	11.38	23.60	30.10
41	19.10	18.04	7.78	10.83	8.01	5.84	25.68	13.61	47.77
42	5.00	14.89	10.61	24.04	20.61	16.01	8.38	8.17	8.09
43	30.15	49.56	41.26	50.62	73.42	29.30	42.13	18.56	45.21
44	23.98	33.21	3.83	12.45	45.83	10.92	21.84	17.89	21.72
Max	82.23	91.61	108.58	86.79	114.57	78.34	74.83	53.09	86.29
Min	5	13.98	3.83	3.86	3.65	4.29	2.25	8.17	7.14
Average	19.81	37.33	26.14	25.65	42.86	22.92	21.54	25.04	28.47
SD	12.36	16.94	20.13	16.63	25.57	15.01	13.73	11.17	15.24

Table 4(b). Yearly (2006–2013) value of post-monsoon water quality index.

Sl. no.	WQI_{2005}	WQI_{2006}	WQI_{2007}	WQI_{2008}	WQI_{2009}	WQI_{2010}	WQI_{2011}	WQI_{2012}	WQI_{2013}
1	—	8.37	34.04	21.94	9.34	4.72	14.18	18.21	26.62
2	—	5.85	45.30	22.36	22.27	14.07	23.01	22.81	25.11
3	—	2.25	19.94	28.50	2.89	2.26	4.07	2.79	8.11
4	—	6.57	62.48	80.72	53.63	56.09	63.42	60.43	25.46
5	—	2.62	42.02	31.74	17.94	4.21	13.77	8.06	28.89
6	—	5.43	47.44	35.62	19.51	15.12	33.05	26.03	25.16
7	—	6.55	43.13	31.43	31.04	7.53	18.74	19.84	24.24
8	—	12.82	31.80	46.53	37.71	6.91	26.26	27.00	13.99
9	—	3.26	13.47	34.53	17.98	7.16	20.35	12.76	16.49
10	—	2.46	13.22	23.86	3.48	2.00	4.44	6.66	6.82
11	—	9.91	40.59	24.13	24.88	10.97	22.94	22.24	28.59
12	—	9.66	52.77	26.22	21.73	25.85	25.11	25.38	27.45
13	—	3.11	21.79	26.37	5.84	6.68	9.25	9.76	15.42
14	—	8.87	35.70	24.46	29.29	16.68	21.28	13.28	49.39
15	—	1.72	23.81	35.71	20.27	12.62	32.23	11.60	35.08
16	—	4.72	30.71	32.96	12.05	6.89	26.62	8.86	23.68
17	—	4.86	30.23	33.27	23.89	25.47	34.21	28.11	23.32
18	—	6.88	18.01	25.67	9.86	2.81	14.42	9.23	21.10
19	—	2.90	34.37	12.09	4.54	2.50	4.42	3.40	8.29
20	—	11.73	27.27	31.88	12.87	6.51	23.64	11.17	23.10
21	—	7.36	17.01	45.05	24.08	26.85	24.75	13.80	47.03
22	—	5.48	45.37	32.69	11.33	7.32	20.64	8.12	69.52
23	—	5.09	30.92	49.90	16.72	47.03	26.15	46.27	27.18
24	—	20.24	25.69	30.47	7.43	4.57	12.16	8.52	21.42
25	—	2.36	65.26	56.73	19.12	12.84	19.43	22.68	26.37
26	—	3.97	27.03	31.55	12.55	14.97	10.98	24.84	32.03
27	—	16.80	27.61	28.93	19.46	14.91	18.30	20.41	39.51
28	—	12.52	23.93	51.79	41.13	30.00	47.14	49.99	32.78
29	—	2.57	58.19	33.38	17.68	9.71	19.28	14.67	32.70
30	—	3.17	32.62	32.97	19.33	13.16	24.96	19.32	24.31
31	—	4.19	50.69	27.06	12.43	7.29	49.27	18.97	26.77
32	—	9.74	20.56	44.08	26.11	19.97	32.36	35.13	44.00
33	—	5.05	23.44	53.97	25.23	26.19	27.47	39.10	42.01
34	—	2.76	52.47	61.20	33.17	26.55	45.71	53.25	30.47
35	—	3.91	46.80	27.04	5.56	25.11	16.16	20.42	38.22
36	—	6.48	55.02	28.88	3.73	41.03	75.08	27.09	56.23
37	—	5.30	38.47	25.92	11.02	11.68	21.39	20.36	33.43
38	—	6.88	29.28	25.02	15.26	8.87	19.52	23.83	29.73
39	—	8.30	22.08	32.88	16.49	13.28	22.55	29.37	60.76
40	—	4.56	27.27	8.19	12.21	7.78	18.04	16.91	47.01
41	—	7.89	23.85	18.02	27.01	5.91	27.87	28.21	36.06
42	—	2.61	13.26	23.86	3.55	2.00	4.40	6.66	6.82
43	—	6.12	31.19	65.82	8.91	18.37	48.26	40.29	74.55
44	—	9.44	24.47	19.55	11.98	8.66	15.39	12.63	55.75
Max		20.24	65.26	80.72	53.63	56.09	75.08	60.43	74.55
Min		1.72	13.22	8.19	2.89	2	4.07	2.79	6.82
Average		6.44	33.65	33.75	17.78	14.57	24.61	21.56	31.61
SD		3.95	13.58	14.18	10.84	12.11	14.83	13.42	15.57

by figure 3(a–b). The maximum average is 42.86 (WQI_{2009}) and minimum average 19.81 (WQI_{2005}) for pre-monsoon season compared to maximum average of 33.75 (WQI_{2008}) and minimum average of 6.44 (WQI_{2006}) in the post-monsoon season.

WQI results show that few wells are also crossing the 4th category (76–100) as highly polluted (poor) (Brown *et al.* 1972; Chatterjee and Raz-iuddin 2002): well no. 4 ($WQI_{Pre2008} = 78.88$), 5 ($WQI_{Pre2005} = 82.23$), 22 ($WQI_{Pre2008} = 86.79$), 23 ($WQI_{Pre2009} = 87.15$), 34 ($WQI_{Pre2006} = 91.61$ and $WQI_{Pre2007} = 108.58$) and well no. 35 ($WQI_{Pre2013} = 86.29$). Well no. 34 shows slight higher yearly fluctuations from 4th to 5th category ($WQI > 100$, unsuitable/unsafe for drinking) during pre-monsoon period (figure 3a). Overall, from the WQI analysis of pre-monsoon (2005–2013), results outline that majority of wells are in category of 1st (excellent) and 2nd (good).

WQI of post-monsoon period (2006–2013) highlights that 11 wells (well no. 4 ($WQI_{Post2007} = 62.48$, $WQI_{Post2009} = 53.63$, $WQI_{Post2010} = 56.09$, $WQI_{Post2011} = 63.42$ and $WQI_{Post2012} = 60.43$), well no. 12 ($WQI_{Post2007} = 52.77$), 22 ($WQI_{Post2013} = 69.52$), well no. 25 ($WQI_{Post2007} = 52.77$), well no. 28 ($WQI_{Post2007} = 51.79$), well no. 29 ($WQI_{Post2006} = 58.19$), well no. 33 ($WQI_{Post2008} = 53.97$), well no. 34 ($WQI_{Post2007} = 52.47$, $WQI_{Post2008} = 61.2$ and $WQI_{Post2012} = 53.25$), well no. 36 ($WQI_{Post2011} = 75.08$ and $WQI_{Post2013} = 56.23$), well no. 39 ($WQI_{Post2013} = 60.76$), well no. 43 ($WQI_{Post2013} = 74.55$) and well no. 44 ($WQI_{Post2013} = 55.75$) are lying under the 3rd category ($51 < WQI < 75$) (figure 3b). In post-monsoon, the WQI shows that well no. 4, has fluctuating behaviour from 3rd to 4th category (very poor, $76 < WQI < 100$) during 2008. The wells in post-monsoon are also falling in category of 1st (excellent) and 2nd (good). The WQI values generally have low values in the post-monsoon season, which suggest that due to rainfall, the groundwater water table gets recharged, hence the dilution is high. The high values of WQI at these stations have been reported mainly due to higher values of iron, nitrate, total dissolved solids, hardness, fluorides, bicarbonate and manganese in the groundwater.

5.3 Calcium (Ca^{2+})

Silicate weathering is the dominant process for the supply of calcium ions to the groundwater (figure 3a). In addition to silicate weathering, the

carbonate weathering process is also a contributor for increasing of calcium ions in this groundwater. Sodium and calcium ions are often involved in ion exchange processes. Calcium ions typically displace the sodium ions from the clay minerals as the groundwater flows through aquifers. This exchange process causes the loss of calcium concentration in groundwater and enhancement of sodium concentration (Singh *et al.* 2013a,b; Rawat *et al.* 2012a,b; Rawat and Tripathi 2015; Tripathi *et al.* 2016). From table 5(a), average value, positional average and mode of Calcium are 64.31, 52.0 and 32.0, respectively. The time series (2005–2013) is showing variation in mean, median and mode values (figure 4a). During pre-monsoon SD is high (51.22); thus, it suggests that the sampling year and sampling locations have high variability. It is positively skewed and the curve is platykurtic. Calcium has anti-persistent behaviour (or negative autocorrelation) with EC because of low value of H (0.45~0.50). According to PI value of Ca^{2+} (0, table 5a), Ca^{2+} is close to the Brownian motion (unpredictable). From table 5(b), average value, positional average and mode of Ca^{2+} are 62.74, 48.0 and 24.0, respectively. Similarly, Ca^{2+} has variation in mean, median and mode values in post-monsoon (2006–2013) (figure 4b). SD value is also high (53.56); thus, the values of Ca^{2+} are not close to each other. Ca^{2+} is positively skewed with a platykurtic curve. Again, Ca^{2+} has anti-persistent behaviour (or negative autocorrelation) with EC ($H = 0.47$). PI value of Ca^{2+} is 0 (table 4b), therefore Ca^{2+} is showing the Brownian motion (unpredictable).

5.4 Magnesium (Mg^{2+})

Calcium and magnesium ions present in groundwater are particularly derived from leaching of limestone, dolomites, gypsum and anhydrites, whereas, the calcium ions are also derived from cation exchange process (Garrels 1976; Singh *et al.* 2015). The concentration of magnesium ion in this groundwater samples is relatively high when compared to calcium ion concentration and the magnesium concentration is mostly due to weathering of magnesium minerals and leaching of dolomites. The average of Mg^{2+} (50.26), median (35.00) and mode values (29.00) are different; thus, the curve does not follow normal behaviour. SD is high (70.61), thus the data exhibit normal behaviour. Standard deviation (15.181) is suggesting that the data are not close to each other. The skewness is positive (9.43),

Figure 3. (a) Yearly (2005–2013) value of pre-monsoon water quality index. (b) Yearly (2006–2013) value of post-monsoon water quality index.

thus the curve is moderately symmetrical and platykurtic. Mg^{2+} has anti-persistent behaviour with EC ($H = 0.47 \sim 0.5$). PI value of Magnesium is $0.1 \sim 0$ (table 5b), Mg^{2+} shows the Brownian motion (unpredictable) nature. Median (35.00) and mode values (32.00) are close, but average (47.93) is different; thus, the curve does not follow normal behaviour. SD is high (41.70), thus the data exhibit normal behaviour. SD (41.70) suggests that the data are not close to each other. The skewness value (2.52) is positive, thus the curve is moderately symmetrical and platykurtic. Mg^{2+} has negative autocorrelation with EC ($H = 0.48$) during post-monsoon (2006–2013). PI value of Mg is 0 (table 5b), Mg^{2+} has the Brownian motion (unpredictable) nature.

5.5 Sodium (Na^+)

The possible source of sodium ions in groundwater is due to dissolution of rock salts and weathering of sodium bearing minerals and weathering of

silicate-bearing minerals (Srinivasamoorthy *et al.* 2008). Average and median values are nearly similar, whereas mode value is different and hence the sodium data show non-normal behaviour. SD value is high (125.89), it exhibits that the sample points are not close to each other and the local geology plays a critical role. The skewness (3.56) suggests that the curve is moderately symmetrical and kurtosis value is quite high (125.89); thus, the nature of curve is platykurtic. Na^+ has mean reversion behaviour with EC, and Mg^{2+} during pre-monsoon period (2005–2013) because of low value of H ($0.45 \sim 0.5$) for EC and 0.9 for Mg^{2+}). From table 5(b), PI value of Na^+ is 0.1 which indicates Na^+ towards the Brownian motion (unpredictable) nature. Average, median and mode values are different and thus the data show non-normal behaviour. SD value is high (95.63), which reveals that the groundwater sample points are not close to each other. SD (95.63) suggests that the curve is unsymmetrical and kurtosis value is quite (3.64) high;

Table 5. Regression equations, coefficient of correlation, Hurst exponent, fractal dimension and predictability index between water parameters during (a) pre-monsoon (2005–2013) and (b) post-monsoon (2006–2013).

Y	Parameters (X)	Regression equation	r^2	r	m_{yx}	H	D	PI
(a) Pre-monsoon (2005–2013)								
Ca ²⁺	EC	0.03 * X + 23.52	0.42	0.648	0.03	0.49	1.52	0.0
Mg ²⁺	EC	0.057 * X – 25.87	0.771	0.878	0.06	0.47	1.53	0.1
Na ⁺	EC	0.103 * X + 3.666	0.783	0.885	0.10	0.45	1.55	0.1
	Mg ²⁺	1.189 * X + 80.77	0.44	0.667	1.19	0.09	1.91	0.8
Cl [–]	Mg ²⁺	4.334 * X + 18.23	0.87	0.933	4.33	1.67	0.33	2.3
	EC	0.289 * X – 146.7	0.903	0.95	0.29	0.36	1.64	0.3
	Na ⁺	2.061 * X – 53.56	0.625	0.791	2.06	0.53	1.47	0.1
	Ca ²⁺	3.671 * X – 0.031	0.328	0.573	3.67	1.34	0.66	1.7
SO ₄ ^{2–}	Ca ²⁺	1.792 * X – 22.69	0.35	0.592	1.79	0.40	1.60	0.2
	Na ⁺	0.829 * X – 23.99	0.453	0.674	0.83	0.09	1.91	0.8
	EC	0.1 * X – 39.7	0.483	0.695	0.10	0.45	1.55	0.1
TDS	Mg ²⁺	8.09 * X + 376.2	0.764	0.874	8.09	3.55	–1.55	6.1
	Cl [–]	1.87 * X + 341.2	0.882	0.939	1.87	0.44	1.57	0.1
	Na ⁺	4.669 * X + 126.6	0.809	0.9	4.67	1.83	0.17	2.7
	SO ₄ ^{2–}	3.106 * X + 495.3	0.542	0.737	3.11	1.05	0.95	1.1
	Ca ²⁺	8.168 * X + 257.6	0.41	0.64	8.17	3.58	–1.58	6.2
	EC	0.601 * X – 13.4	0.984	0.992	0.60	0.20	1.80	0.6
(b) Post-monsoon (2006–2013)								
Ca ²⁺	EC	0.047 * X + 3.102	0.598	0.774	0.047	0.48	1.52	0.0
Mg ²⁺	EC	0.04 * X – 2.02	0.693	0.832	0.04	0.48	1.52	0.0
Na ⁺	EC	0.09 * X + 12.98	0.668	0.818	0.09	0.46	1.55	0.1
Cl [–]	Ca ²⁺	3.428 * X + 8.404	0.568	0.754	3.428	1.21	0.79	1.4
	Mg ²⁺	5.003 * X – 16.28	0.733	0.754	5.003	2.00	0.00	3.0
	EC	0.26 * X – 105	0.878	0.937	0.26	0.37	1.63	0.3
	Na ⁺	1.823 * X – 5.363	0.512	0.716	1.823	0.41	1.59	0.2
HCO ₃ [–]	Na ⁺	0.48 * X + 184.5	0.142	0.611	0.48	0.26	1.74	0.5
SO ₄ ^{2–}	EC	0.087 * X – 33.41	0.443	0.666	0.087	0.46	1.54	0.1
TDS	Na ⁺	4.296 * X + 185.7	0.719	0.848	4.296	1.65	0.35	2.3
	Cl [–]	1.82 * X + 318.2	0.837	0.915	1.82	0.41	1.59	0.2
	SO ₄ ^{2–}	2.99 * X + 98.4	0.496	0.705	2.99	1.00	1.01	1.0
	EC	0.553 * X + 36.26	0.976	0.988	0.553	0.22	1.78	0.6
	Ca ²⁺	6.942 * X + 289.6	0.589	0.768	6.942	2.97	–0.97	4.9
	Mg ²⁺	9.308 * X + 279	0.642	0.801	9.308	4.15	–2.15	7.3

thus, the nature of curve is platykurtic. Na⁺ has anti-persistent behaviour with EC during pre-monsoon period (2006–2013) and towards the unpredictable nature.

5.6 Chloride (Cl[–])

The natural process such as weathering, dissolution of salt deposits, and irrigation drainage return flow are responsible for chloride content in the groundwater. Average (236.10), median (149.0) and mode (50.0) values are not equal, and thus the data

show abnormal behaviour. *SD* value (328.05) shows that the sample points are not close to each other. Skewness value (7.28) suggests that the curve is unsymmetrical and the high kurtosis value also defines nature of curve as platykurtic. Chloride has persistent behaviour with EC but with Mg²⁺, Na⁺ and Ca²⁺ having anti-persistent behaviour due to greater value of *H* (1.67, 0.53 and 1.34, respectively) from 0.5 during pre-monsoon series from 2005 to 2013. According to *PI* value of Na⁺ (0.1~0, table 5a), Na is towards the Brownian motion (unpredictable).

Figure 4. Graphical representation of statistical analysis of (a) pre-monsoon water parameters (2005–2016) and (b) post-monsoon water parameters (2006–2016).

The average value, positional average and mode of Cl^- were 223.54, 135.0 and 53.0, respectively. Figure 3(b) is showing much variation in mean, median and mode values during post-monsoon data series (2006–2013), thus datasets have abnormal behaviour. *SD* value of Cl^- (during post-monsoon) shows that the sample points (or wells) are not close to each other. Less skewness value (2.46) suggests that the curve is moderately symmetrical and kurtosis value is revealing curve is platykurtic. Chloride has anti-persistent behaviour with EC and Na^+ (table 5b), but with Ca^{2+} and Mg it has persistent (a positive autocorrelation) behaviour due to greater value of *H* (1.21 and 2.00, table 5b) during post-monsoon series from 2005 to 2013.

5.7 Sulfate (SO_4^{2-})

Sulfate ion concentrations are probably derived from weathering of sulfate and gypsum-bearing

sedimentary rocks (Elango *et al.* 2003; Jeevanandam *et al.* 2006). Average value, positional average and mode of SO_4^{2-} were 92.55, 57.00 and 48.00, respectively. There is variation in average, median and mode values and thus the data show unusual behaviour. *SD* value (154.96) exhibits that the observation values of SO_4^{2-} from wells (or sample points) are not close to each other. Skewness value (5.45) suggests that the curve is towards the symmetrical and kurtosis value is higher (32.69); thus, the curve is platykurtic. SO_4^{2-} has anti-persistent behaviour with Ca^{2+} , Na^+ and EC during pre-monsoon. Average (76.04), median (49.50) and mode (96.00) values are not equal, and thus the data does not show normal behaviour. *SD* value (114.30) shows that the sample points are not close to each other. Skewness value (6.05) suggests that the curve is unsymmetrical and the high kurtosis value explains the nature of curve to be platykurtic. SO_4^{2-} has anti-persistent behaviour with EC because of less value of *H* (0.46) during

post-monsoon series from 2005 to 2013. According to PI value of SO_4^{2-} ($0.1 \sim 0$, table 5a), SO_4^{2-} moves toward the Brownian motion (unpredictable).

5.8 Total dissolved solids (TDS)

The total of major cations and anions present in groundwater represents the total dissolved solids (Rawat *et al.* 2012b; Singh *et al.* 2013a,b; Rawat and Tripathi 2015; Jacintha *et al.* 2016; Tripathi *et al.* 2016). The concentration of ions in groundwater depends on many factors and processes that occur in the aquifer system (Singh *et al.* 2009). The identification of geochemical processes is investigated by the study of concentrations of various major ions present in groundwater. It is a general indicator of water quality generally used to understand the amount of contaminant present in the groundwater (Jeelani *et al.* 2014). Mean (782.90), median (648.00) and mode (304.00) values are different; thus, the curve does not follow normal behaviour. SD value is high (653.39), thus the values of TDS are not close to each other. It is positively skewed and the curve is platykurtic. TDS has persistent behaviour with Mg^{2+} , Na^+ , SO_4^{2-} and EC, and anti-persistent behaviour with Ca^{2+} during pre-monsoon (2005–2013). During post-monsoon (2006–2013), average value (725.24), positional average (593.00) and mode (380.00) is not in close ranges, much variation exists among them, thus the data show unusual behaviour. SD value (484.41) exhibits that the observation value of TDS from wells (or sample points) are not close to each other. Skewness value (1.86) suggests that the curve is close to symmetrical and kurtosis value is also low (4.18); thus, the curve is platykurtic. TDS has anti-persistent behaviour with Cl^- , and EC (towards unpredicted nature) and persistent behaviour with Na^+ , SO_4^{2-} , Ca^{2+} and Mg^{2+} during post-monsoon time period (2006–2013).

5.9 Bicarbonate (HCO_3^-)

For irrigation purposes, the suitability of groundwater is controlled by the quantity of bicarbonate and carbonate present in water in excess of alkaline earths ($Ca^{2+} + Mg^{2+}$) (Pal and Poonia 1979). When the total of carbonates and bicarbonates is in excess of calcium and magnesium, there may be possibility of complete precipitation of Ca^{2+} and Mg^{2+} ions (Rawat *et al.* 2012b; Singh *et al.* 2013a,b, 2015; Tripathi *et al.* 2016). The availability of carbonate minerals in the recharge

areas and silicate weathering are the main factors, which lead to increase of carbonates and bicarbonate concentration in the groundwater (Elango *et al.* 2003). Average (244.94), median (226.00) and mode (268.00) values are almost in the same range, and thus the data show normal behaviour. Standard deviation value ($122.0 = 49.8\%$ of average value) explains that the sample data are not spread. The curve is skewed and platykurtic. HCO_3^- has anti-persistence behaviour with Na^+ due to H (0.26) value < 0.5 during post-monsoon (table 5b). But during pre-monsoon, HCO_3^- has less significant correlation coefficient (r) with TDS, therefore, HCO_3^- has no regression equation with TDS.

6. Conclusion

Weathering processes and anthropogenic inputs are the two main contributors for changing the geochemical composition of the groundwater. The statistical analysis result highlights that all groundwater parameters are having platykurtic curve. The Brownian time series behaviour exists for Ca^{2+} with EC; Mg^{2+} with EC; SO_4^{2-} with EC and TDS with EC which continues during pre- and post-monsoon from 2005 to 2013. The persistent behaviour (a positive autocorrelation) exists between Cl^- with Mg^{2+} , Cl^- with Ca^{2+} , TDS with Na^+ , TDS with SO_4^{2-} and TDS with Ca^{2+} in the times series of hydrogeochemical parameters of groundwater in pre- and post-monsoon because of higher value of $H (> 1)$. The anti-persistent behaviour (a negative autocorrelation) exists of Cl^- with EC, TDS with EC during pre- and post-monsoon due to low value of H . The average of hydrogeochemical parameters is close to the prescribed WHO (2006) standard for the period (2005–2013). The WQI values of pre- and post-monsoon of 44 monitored wells show that majority of sites fall in the category of suitable, polluted and moderately polluted. Few sites also fall in the category of highly polluted and unfit in the pre-monsoon. Whereas, there is only one site in the post-monsoon season which falls in the category of highly polluted in the year 2008. WQI patterns fluctuate for each year. The water of the post-monsoon season is less polluted as compared to pre-monsoon season and this is attributed to recharge of groundwater table after rainfall. For individual well spread throughout the study area land use subcontinent,

our studies quantify the inconsistency and discrepancy between predictability of groundwater physicochemical parameter *vs.* any other groundwater physicochemical parameter using regression equation, *H*, *D* and *PI* analysis. This analysis reveals that some groundwater physicochemical parameter of the study area can predict other groundwater physicochemical parameter with strong *r* and *r*². Groundwater contamination is very complex due to natural and anthropogenic phenomena. However, in this work, the complexity has been studied from a different viewpoint using statistical tests *m_{xy}*, *r*, *r*², *H*, *D*, and *PI*. The groundwater quality analyses indicate that the local geology, climate plays a dominant role in controlling the groundwater chemistry and the dissolution of carbonate rocks and silicate weathering and ion exchange process controls the distribution of major ions in the water.

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