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# Evaluation of Groundwater Quality for Drinking Purpose using Different Water Quality Indices in Parts of Gautam Budh Nagar District, India

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Water Quality Index (WQI) is a mathematical value for quality of water, which includes the concentration of a number of constituents present in it. Chemical and biological measures of water quality are used to represent water quality index. Measured value of the selected parameters, ideal concentration of that parameter in pure water and standard value given by different quality control organizations are used to determine this number. In the present study, three indexing methods; Weighted Arithmetic Water Quality Index (WAWQI), Groundwater Quality Index (GWQI) and Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) were used to calculate water quality index of groundwater. A hydrochemical analysis of 22 groundwater samples was conducted to evaluate the quality of groundwater for drinking purpose. Ten hydrochemical parameters were selected for computing WQIs of groundwater samples and BIS standards were used for standardization. Analytical results show that 100 % of samples have magnesium and total hardness above the acceptable limit of BIS (10500, 2012). The mean concentration of nitrate was found 196.96 ± 9.3.18 mg/L. Spatial distribution of various parameters shows that south-east part of study area has contaminated groundwater. The results of water quality index shows that drinking water quality of 82 % (WAWQI), 95 % (GWQI) and 77 % (CCME WQI) of groundwater samples were poor to unsuitable type. Water quality index map also reveals that groundwater of village Badhpura, Dhoom Manikpur, Dairy Maccha, Khera Dharampura, Bisrakh road, Duryai and Dujana of district Gautam Budh Nagar of India, was not fit for human consumption.

**Keywords: Water quality index, Weighted arithmetic water quality index, Groundwater quality index, Drinking water.**

## INTRODUCTION

Water is an essential component of our ecosystem. Water after air is the most important requirement for the survival of life. Easy access to safe drinking water is the prime importance to everyone. Groundwater is the main natural resource to fulfill this requirement [1]. In India, a major part of extracted groundwater (89 %) is used for irrigation, 9 % of it for domestic use and rest of 2 % for industrial purpose [2]. The quality of this important water resource is affected by three main factors *viz.* agricultural activities, industrialization and urbanization hence monitoring and assessment of water quality at regular intervals is very essential. The water quality index (WQI) system is a widely used technique to show the quality of water that offers a numeric, easy to understand and reproducible number, which signifies the changes in the important parameters of water [3]. It can be expressed as a mathematical figure which demonstrates the combine effect of characterstic hydrochemical and biological parameters on quality of water. It is an effective medium for evaluation of groundwater quality as it summarize the huge water quality data into a simple numerical score [4]. After the development of WQIs in a particular area, it can be applied to examine the environmental conditions of that area and also help policy makers to decide strategy in that area. WQI is the only tool by which the highly multi-attribute and multivariate concept of water quality can be conveyed to lay persons in the form of a numeric score.

Initially in 1965, Horton [5] proposed that different physical, chemical and biological parameters can be combined into an overall water quality index. Brown *et al.* [6] put forward a general way for the computation of water quality index. Walski and Parker [7] used an exponential function to illustrate the sub indices of various quality variables. Deininger extended it for the Scottish Development Department [8]. The sub-index of each hydrochemical parameter was combined into Pearson type 3-distribution function by Landwehr [9]. The exponential expression was revised by Bhargava [10]. A power function for each of sub-index was used by Dinius [11]. Subsequently various improvements have been done by various scientists to calculate water quality index [12-17]. The different water quality indices are used by different countries *e.g.* US National Sanitation Foundation Water Quality index (NSF WQI), British Columbia Water Quality Index (BCWQI), Canadian Council of Ministers of the Environment Water Quality Index (CCMEWQI), Nemerow and Sumitomo′s Pollution Index, Oregon Water Quality Index (OWQI), Weighted Arithmetic Water Quality Index (WAWQI), *etc*. [18-22].

Basically formulation of WQI is done in four steps. Step one is the selection of parameters which majorly affect the quality of water. In second step, each hydrochemical parameter is converted into an equal scale of unit. Third step (not essential to all methods) is the assignment of weightage to each of the parameter and last fourth step is the combination of subindices for each parameter into a final index value [23]. Different researchers used different methods to calculate WQI. Vasanthavigar *et al*. [24] calculated WQI of 148 groundwater samples by using BIS (Bureau of Indian Standards) standards to quantify overall water quality for drinking purpose in Thirumanimuttar sub-basin of Tamilnadu state of India. The pre-monsoon groundwater samples showed poor water quality in comparison to post-monsoon samples. Babiker *et al*. [25] proposed a GIS-based groundwater quality index (GWQI) for Nasuno basin, Tochigi Prefecture, Japan by using WHO standards and used seven parameters ($Cl^-$, $Na^+$, $Ca^{2+}$, $Mg^{2+}$, $SO_4^{2-}$, $NO_3^-$ and TDS) to calculate GWQI. Groundwater is the major source of irrigation and drinking water in current study area. Three methods of calculating water quality index were used to develop WQI of groundwater in current study area- Weighted Arithmetic Water Quality Index (WAWQI), Groundwater Quality Index (GWQI) and Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI).

## EXPERIMENTAL

The location of study area is 28°56' to 28°63' N latitude and 77°47' to 77°54' E longitude in northern part of India. The district is separated from Haryana state and Delhi city by river Yamuna. Soil type of study area is pure sand (Bhur), pure clay (Matiar) and a mixture of both (Dumat and Loam). Fertility of soil depends upon the ratio of sand and clay in it. Most of the parts of district have alluvial soil which is good for agricultural practices [26]. The climate of this area is sub-humid and the study part of area comes under Yamuna sub-basin. The major river of this area is Yamuna and its tributary rivers: Hindon river and Bhuriya nadi. Major part of land in district is used for agriculture (67.93 %) and 1.4 % covered by forest [27]. A large area of district is extensively populated and agriculture is the major occupation for most of the people. People are mainly depend on groundwater for their daily requirement. Several manufacturing industries are present in villages of Gautam Budh Nagar district. Dumping of industrial wastes in water bodies without proper treatment causes water contamination. The percolation of this contaminated water causes groundwater pollution in this area. Dense industrial setup in unplanned manner is responsible for groundwater pollution of this area [28].

**Samples collection:** Total 22 samples (S1-S22) of groundwater were collected from the study area by simple randomization method from different hand-pumps, tube-wells and borewells. Fig. 1 shows the sampling locations in the different villages (Badhpura, Dhoom Manikpur, Dairy Maccha, Sadopur, Achheja, Khera Dharampura, Talabpur, Duryai, Bishnuli, Dujana and Badalpur) of Gautam Budh Nagar district. These villages are situated near the Chhapraula industrial area of Bisrakh block of the district on the both side of National Highway-34 (NH-34). The standing water was left to run out from the source before collecting the samples. Pre-washed polyethylene bottles were used to collect water samples and stored at 10 ºC for analysis. The pH, turbidity, electrical conductivity (EC), total dissolved solids (TDS), total hardness, total alkalinity, chloride ($Cl^-$), fluoride ($F^-$), sulphate ($SO_4^{2-}$) and nitrate ($NO_3^-$) were analyzed by using the standard methods as recommended by the APHA [29]. The $Ca^{2+}$, $Mg^{2+}$, $CO_3^{2-}$, $HCO_3^-$ and $Cl^-$ concentration were determined by titrimetric method. The concentration of $NO_3^-$ and $F^-$ were determined using ion selective electrode method. Alkali metals (Na, K) concentrations were determined by flame photometry (SYSTRONICS-128 flame photometer). Concentration of $SO_4^{2-}$ was determined by using UV-visible spectrophotometer (Varian BIO-100). The validation of the analytical results was done by using ion balance equation [30].

$$E = \frac{\Sigma_{Cations} - \Sigma_{Anions}}{\Sigma_{Cations} + \Sigma_{Anions}} \times 100$$

where, $\Sigma_{Cations}$ = total cations (meq/L) and $\Sigma_{Anions}$ = total anions (meq/L).

The error percentage (E) for each analyzed water sample was ± 5 %. Contour maps of various hydrochemical parameters and water quality indices were plotted by using Surfer 11. To understand the hydrogeochemical facies of groundwater of study area, Piper plot was generated using AqQA Rockware software.

**Weighted Arithmetic Water Quality Index (WAWQI):** Weighted arithmetic water quality index method is used to determine the quality of water by using selected hydrochemical parameters. The potability of water was analyzed by several researchers by this method [31-34]. Calculation of WAWQI was carried out in this work using Brown′s method [35]. Calculation of WAWQI was peformed in four steps:

**Step-1:** First unit weight ($W_n$) of $n^{th}$ water quality parameter was calculated. Unit weight ($W_n$) is inversely proportional to standard value of $n^{th}$ water quality parameter ($S_n$).

$$W_n = \frac{k}{S_n} \quad (1)$$

where k = proportionality constant and can be determined as follows:

$$k = \frac{1}{\left(\frac{1}{\sum_{i=1}^{n} S_n}\right)} \quad (2)$$

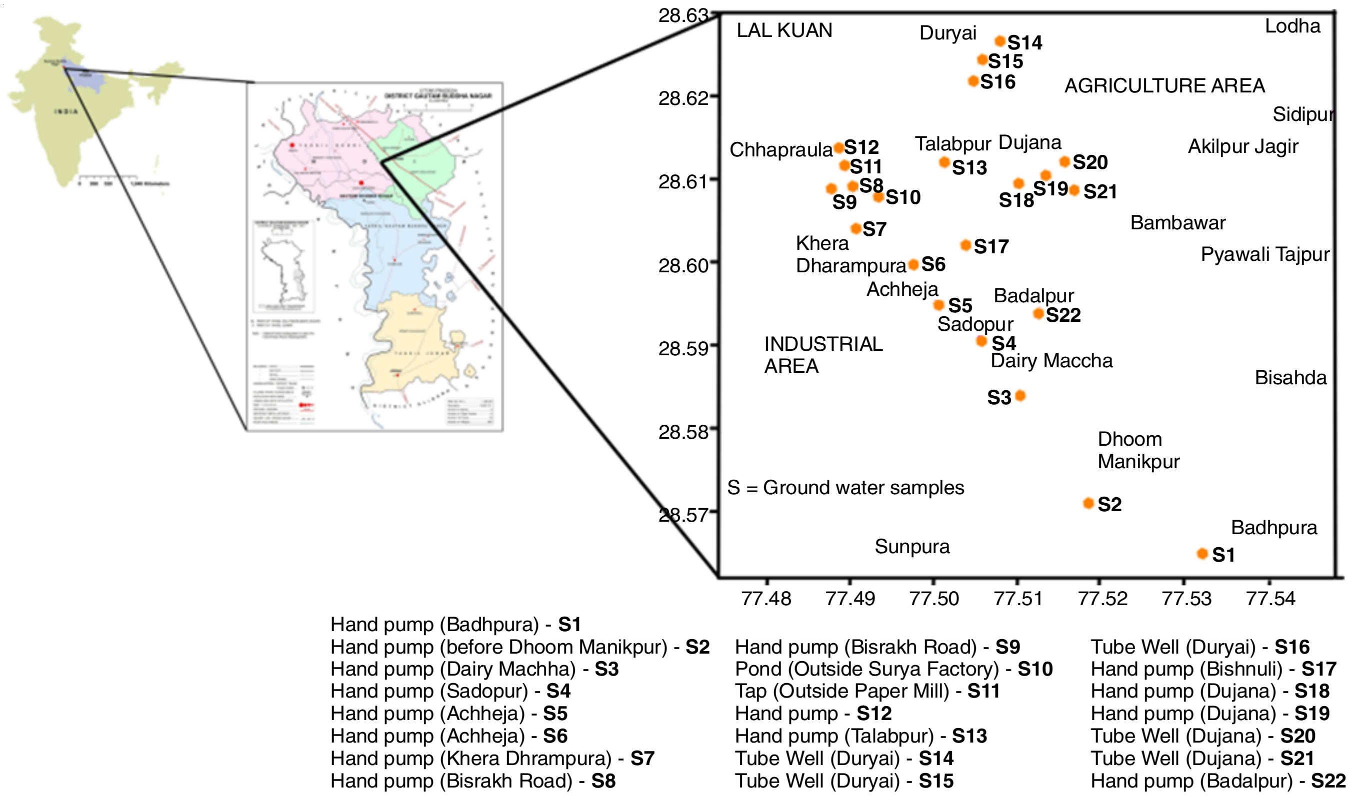


Fig. 1. Sampling locations in study area

**Step-2:** Quality rating ($Q_n$) of n$^{th}$ water quality parameter for all the selected parameters was calculated as follows:

$$Q_n = \frac{(V_{actual} - V_{ideal})}{(S_{standard} - V_{ideal})} \times 100 \quad (3)$$

where $V_{actual}$ = actual value of n$^{th}$ water quality parameter for each sample, $V_{ideal}$ = ideal value for n$^{th}$ parameter in pure water. ($V_{ideal}$ = 0 for all parameters except pH = 7, for DO =14.6 mg/L, $S_{standard}$ = standard value of n$^{th}$ water quality parameter.

**Step-3:** Overall WAWQI was calculated by combining unit weight (Wn) and quality rating ($Q_n$) (eqn. 4):

$$WAWQI = \frac{Q_n W_n}{W_n} \quad (4)$$

For the calculation of WAWQI of collected samples, 10 parameters were chosen (pH, $Ca^{2+}$, $Mg^{2+}$, TH, $Cl^-$, $F^-$, $SO_4^{2-}$, $NO_3^-$, TDS and turbidity). Standard values for these parameters given by BIS [36] and unit weight (Wn) of each parameter are given in Table-1. Based on standard method of weighted arithmetic water quality index, water quality rating is given in Table-2.

**Groundwater Quality Index (GWQI):** This method of calculating water quality index is simple and fairly accurate. The methodology of GWQI was first given by Ribeiro *et al.* [37]. GWQI was calculated in five steps:

**Step-1:** Ten parameters (pH, $Ca^{2+}$, $Mg^{2+}$, TH, $Cl^-$, $F^-$, $SO_4^{2-}$, $NO_3^-$, TDS and turbidity) were selected to calculate GWQI. A weightage ($w_i$) of 1 to 5 was given to each parameter according to its comparative contribution in water quality as shown in Table-3.

**Step-2:** The relative weight ($W_i$) for each parameter was calculated by the following expression:

TABLE-1
BIS DRINKING WATER STANDARDS (10500, 2012)
AND UNIT WEIGHT OF EACH PARAMETER

| Parameters | Standard value ($S_n$) (BIS 10500, 2012) | Unit weight ($W_n$) |
|---|---|---|
| pH | 6.5 | 0.068720 |
| $Ca^{2+}$ | 75 | 0.005956 |
| $Mg^{2+}$ | 30 | 0.014889 |
| TH | 200 | 0.002233 |
| $Cl^-$ | 250 | 0.001787 |
| $F^-$ | 1 | 0.446681 |
| $SO_4^{2-}$ | 200 | 0.002233 |
| $NO_3^-$ | 45 | 0.009926 |
| TDS | 500 | 0.000893 |
| Turbidity | 1 | 0.446681 |
| $\Sigma W_n$ | | 1.000000 |
| Constant of proportionality (k) = 0.446681 | | |

$$w_i = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad (5)$$

The calculated values of relative weight ($w_i$) are given in Table-3.

**Step-3:** Quality rating scale ($Q_i$) for individual parameter is the percentage of actual value to the standard value of that parameter.

$$Q_i = \frac{C_i}{S_i} \times 100 \quad (6)$$

where $C_i$ = actual value of analyzed hydrochemical parameter in the water sample (mg/L), and $S_i$ = standard value for each hydrochemical parameter (mg/L) [36].

**Step-4:** Subindex ($SI_i$) for each parameter = $W_i \times Q_i$

TABLE-2
WATER QUALITY RATING AS DIFFERENT WATER QUALITY INDEX METHOD

| Water quality index level | Water quality status |
|---|---|
| As Weighted Arithmetic Water Quality Index (WAWQI) | |
| 0-25 | Excellent water quality |
| 26-50 | Good water quality |
| 51-75 | Poor water quality |
| 76-100 | Very poor water quality |
| > 100 | Unsuitable for drinking |
| As Groundwater Quality Index (GWQI) | |
| < 50 | Excellent |
| 50-100 | Good water |
| 100-200 | Poor water |
| 200-300 | Very poor water |
| > 300 | Water unsuitable for drinking |
| As Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI) | |
| 0-44 | Poor water quality |
| 45-59 | Marginal water quality |
| 60-79 | Fair water quality |
| 80-94 | Good water quality |
| 95-100 | Excellent water quality |

TABLE-3
RELATIVE WEIGHT OF HYDROCHEMICAL PARAMETERS

| Chemical parameters | Standard values | Weight ($w_i$) | Relative weight ($W_i$) |
|---|---|---|---|
| pH | 6.5-8.5 | 4 | 0.1143 |
| $Ca^{2+}$ | 75 | 2 | 0.0571 |
| $Mg^{2+}$ | 30 | 2 | 0.0571 |
| TH | 200 | 2 | 0.0571 |
| $Cl^-$ | 250 | 3 | 0.0857 |
| $F^-$ | 1 | 4 | 0.1143 |
| $SO_4^{2-}$ | 200 | 4 | 0.1143 |
| $NO_3^-$ | 45 | 5 | 0.1429 |
| TDS | 500 | 5 | 0.1429 |
| Turbidity | 1 | 4 | 0.1143 |
| | | $\Sigma w_i = 35$ | $\Sigma W_i = 0.9715$ |

**Step-5:** Overall groundwater quality index was computed by aggregating all the subindices for each parameter (eqn. 7). The calculated GWQI values are categorized into five types, excellent water to water unsuitable for drinking (Table-2).

$$GWQI = \Sigma SI_i \quad (7)$$

**Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI):** Canadian Council of Ministers of the Environment water quality index (CCME WQI) is based on upon the specific use of water: drinking, recreation, irrigation, livestock watering, wildlife and aquatic life [38]. The mathematical expression for calculating CCME WQI was given by British Columbia Ministry of Environment, Lands and Parks. It was later revised by Alberta Environment taking into consideration three elements: scope, frequency and amplitude. A rating scale of 0 to 100 is given to the index value, which represents worst to best quality of water. This rating scale is divided into five categories [39,40] (Table -2). First three factors scope ($F_1$), frequency ($F_2$) and amplitude ($F_3$) was calculated to compute CCME WQI.

Scope ($F_1$) was calculated by dividing the number of variables which do not attain quality objectives by the total number of measured variables and then multipling the result by 100.

$$F_1 = \frac{\text{Number of failed variables}}{\text{Total number of variables}} \times 100 \quad (8)$$

Frequency ($F_2$) is the percentage of failed tests to the total number of tests.

$$F_2 = \frac{\text{Number of failed tests}}{\text{Total number of tests}} \times 100 \quad (9)$$

Amplitude ($F_3$) is the quantity by which failed tests do not attain their quality objectives. Three steps were used to calculate $F_3$.

(a) Excursion was calculated for two cases: when actual test value was greater than objective and actual test value was lesser than the objective.

$$\text{Excursion}_i = \frac{\text{Failed test value}_i}{\text{Objective}_j} - 1$$

$$\text{(when test value > objective)} \quad (10)$$

$$\text{Excursion}_i = \frac{\text{Objective}_j}{\text{Failed test value}_i} - 1$$

$$\text{(when test value < objective)} \quad (11)$$

(b) Normalized sum of excursions (nse) was calculated by dividing the sum of all excursion by the total number of tests:

$$\text{nse} = \frac{\sum_{i=1}^{n} \text{Excursion}_i}{\text{Number of tests}} \quad (12)$$

(c) $F_3$ was then calculated by an asymptotic function that scales the normalized sum of the excursions from objectives (nse) to yield a result ranging between 0 and 100.

$$F_3 = \frac{\text{nse}}{0.01\text{nse} + 0.01} \quad (13)$$

CCME water quality index was calculated by using $F_1$, $F_2$ and $F_3$ from the above equations.

$$\text{CCMEWQI} = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732} \quad (14)$$

A number 1.732 was used in the equation to regulate the resulting value between the rating scales 1 to 100.

## RESULTS AND DISCUSSION

**Hydrochemical parameters:** The analytical results of hydrochemical parameters (pH, electrical conductivity, turbidity, $Ca^{2+}$, $Mg^{2+}$, $Na^+$, $K^+$, $CO_3^{2-}$, $HCO_3^-$, $Cl^-$, $F^-$, $SO_4^{2-}$, $NO_3^-$, TH and TDS) of 22 groundwater samples collected from Gautam Budh Nagar district of India are given in Table-4.

**pH:** The prescribed standard limit of pH in drinking water [36,41] is 6.5 to 8.5. Although pH of water doesn't affect human health but pH less than 6.5 and pH greater than 8.5 changes water aesthetics. The range of pH in the groundwater samples collected from study area was 7.31-8.97 with an average value of 7.88 ± 0.43 indicating a slightly alkaline nature of groundwater. The spatial distribution of pH in study area is given in Fig. 2a. A dark point on the distribution map of pH, in the north-east part of study area indicates a high value of pH.

TABLE-4
HYDROCHEMICAL PARAMETERS FOR THE SURVEYED GROUNDWATER SAMPLES

| Sample No. | pH | EC (µS/cm) | Turbidity (NTU) | Cations (mg/L) | | | | Anions (mg/L) | | | | | | TH | TDS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | $Ca^{2+}$ | $Mg^{2+}$ | $Na^{+}$ | $K^{+}$ | $CO_3^{2-}$ | $HCO_3^{-}$ | $Cl^{-}$ | $F^{-}$ | $SO_4^{2-}$ | $NO_3^{-}$ | | |
| S1 | 7.31 | 1763 | 48 | 85.60 | 36.64 | 209.40 | 45.45 | 0 | 600.80 | 176.40 | 0.171 | 23.69 | 108 | 363 | 1146 |
| S2 | 7.74 | 1923 | 43 | 13.60 | 116.60 | 176.60 | 12.65 | 0 | 637.30 | 284.20 | 0.256 | 11.84 | 41 | 512 | 1250 |
| S3 | 7.84 | 1222 | 5 | 14.80 | 61.04 | 148.80 | 6.96 | 0 | 257.80 | 68.60 | 1.000 | 43.00 | 318 | 287 | 794 |
| S4 | 7.87 | 561 | 1 | 15.20 | 57.12 | 6.93 | 4.97 | 0 | 174.40 | 29.40 | 0.849 | 33.00 | 102 | 272 | 365 |
| S5 | 7.89 | 1650 | 0 | 105.00 | 46.80 | 198.00 | 32.78 | 0 | 366.00 | 178.00 | 0.922 | 189.00 | 205 | 453 | 1073 |
| S6 | 8.1 | 1878 | 0 | 126.40 | 67.00 | 210.00 | 27.90 | 0 | 340.00 | 260.00 | 1.310 | 267.00 | 180 | 589 | 1221 |
| S7 | 7.37 | 1007 | 3 | 16.80 | 96.24 | 31.19 | 9.50 | 0 | 276.30 | 58.80 | 0.435 | 2.69 | 276 | 436 | 655 |
| S8 | 7.75 | 633 | 1 | 23.60 | 37.44 | 39.16 | 5.43 | 0 | 125.70 | 19.60 | 0.374 | 3.91 | 208 | 212 | 411 |
| S9 | 7.56 | 1810 | 2 | 134.80 | 53.76 | 165.00 | 32.00 | 0 | 289.00 | 265.00 | 0.414 | 143.00 | 173 | 556 | 1177 |
| S10 | 8.04 | 1657 | 28 | 28.00 | 97.92 | 117.80 | 32.30 | 20.52 | 201.40 | 137.20 | 0.472 | 57.20 | 433 | 471 | 1077 |
| S11 | 7.82 | 819 | 0 | 21.60 | 55.68 | 49.63 | 7.60 | 0 | 183.60 | 29.40 | 0.455 | 9.40 | 260 | 282 | 532 |
| S12 | 7.56 | 615 | 2 | 23.20 | 41.52 | 31.32 | 6.41 | 0 | 129.60 | 19.60 | 0.502 | 4.25 | 244 | 228 | 400 |
| S13 | 7.59 | 765 | 0 | 20.00 | 60.96 | 29.31 | 17.34 | 0 | 185.90 | 19.60 | 0.431 | 14.69 | 216 | 300 | 497 |
| S14 | 7.42 | 1059 | 14 | 33.20 | 44.28 | 109.80 | 11.27 | 0 | 232.50 | 39.20 | 0.411 | 85.00 | 308 | 264 | 688 |
| S15 | 7.82 | 845 | 1 | 24.40 | 55.92 | 63.88 | 6.28 | 0 | 228.80 | 39.20 | 0.312 | 4.44 | 210 | 290 | 549 |
| S16 | 7.67 | 727 | 0 | 24.40 | 40.64 | 65.06 | 6.68 | 0 | 249.70 | 19.60 | 0.533 | 1.91 | 201 | 227 | 472 |
| S17 | 7.61 | 1153 | 1 | 15.60 | 49.44 | 129.60 | 7.22 | 0 | 348.50 | 49.00 | 0.455 | 5.20 | 253 | 242 | 749 |
| S18 | 7.84 | 538 | 4 | 32.80 | 33.36 | 14.61 | 5.98 | 0 | 169.50 | 9.80 | 1.090 | 26.00 | 108 | 218 | 350 |
| S19 | 8.97 | 1818 | 0 | 131.20 | 65.28 | 173.30 | 47.13 | 15.39 | 278.60 | 278.00 | 0.352 | 255.00 | 107 | 594 | 1182 |
| S20 | 8.58 | 2102 | 0 | 141.50 | 78.00 | 234.00 | 45.00 | 45.00 | 458.00 | 298.00 | 0.314 | 279.00 | 101 | 672 | 1366 |
| S21 | 8.56 | 1790 | 1 | 123.00 | 45.84 | 184.80 | 49.10 | 17.10 | 230.00 | 267.00 | 0.498 | 298.00 | 71 | 494 | 1164 |
| S22 | 8.51 | 1980 | 1 | 135.00 | 55.00 | 210.00 | 51.00 | 12.00 | 278.00 | 294.40 | 0.426 | 267.00 | 210 | 562 | 1287 |
| Min. | 7.31 | 538 | 0 | 13.6 | 33.36 | 6.93 | 4.97 | 0 | 125.7 | 9.8 | 0.171 | 1.91 | 41 | 212 | 350 |
| Max. | 8.97 | 2102 | 48 | 141.5 | 116.6 | 234 | 51 | 45 | 637.3 | 298 | 1.31 | 298 | 433 | 672 | 1366 |
| Mean | 7.88 | 1287.05 | 7.05 | 58.62 | 58.93 | 118.10 | 21.41 | 5.00 | 283.70 | 129.09 | 0.54 | 92.01 | 196.95 | 387.45 | 836.59 |

**Electrical conductivity:** The electrical conductivity (EC) value of groundwater samples ranged from 538 to 2102 (µS/cm) in study area. Contour mapping of electrical conductivity indicates that the groundwater of central and south-east part of study area have relatively higher values (Fig. 2b). The high EC values of groundwater of villages Badhpura, Dhoom Manikpur, Achheja, Bisrakh road, Dujana and Badalpur showed the percolation of contaminated surface water to ground aquifers.

**Turbidity:** A turbidity of water is due to the presence of suspended matter such as clay, silt, organic and inorganic impurities. High turbidity value makes the water translucent and unacceptable for drinking. High turbidity value has no ill effect on health but if the turbidity is due to organic matter it can cause health hazards. The calculated value of turbidity ranged from 0 to 48 NTU for groundwater samples. Around 41 % of samples of groundwater have turbidity value higher than the acceptable limit of BIS *i.e.* 1 NTU. Sample S1, S2, S10 and S14 have very high value of turbidity 48, 43, 28 and 14, respectively. This indicates that various pollutants were present in groundwater of these sampling sites. These pollutants may be due to dumping of industrial, agricultural and municipal wastes, in the study area. Singh and Hussian [42] also reported that 87 % of groundwater samples in Greater Noida region have turbidity within the acceptable limit of BIS.

**Total dissolved solids (TDS):** The source of total dissolved solids of water can be natural or anthropogenic. Potability of water is considered as excellent which has less than 500 mg/L TDS value. Consumption of water having high TDS for a long time can affect central nervous system of human beings. Its reported value in the groundwater samples ranged from 350 to 1366 mg/L. Around 73 % of samples were above the acceptable limit of BIS (500 mg/L) but all the samples have TDS value below the BIS permissible limit of 2000 mg/L. TDS contour of groundwater samples shows a comparatively high TDS in villages Badhpura, Dhoom Manikpur, Achheja, Bisrakh road, Dujana and Badalpur (Fig. 2c).

**Hardness:** A total hardness (TH) of water (as $CaCO_3$) ranged between 212 to 672 mg/L with an average of 387.59 mg/L in the groundwater samples. All the samples have total hardness above the standard acceptable limit given by BIS (200 mg/L). Samples having TH < 75 are cosidered as soft water, 75-150 moderately hard, 150-300 hard and greater than 300 very hard [43]. Out of 22 groundwater samples which have been collected 10 samples have hard water and 12 samples have very hard type of water.

**Calcium:** BIS sets an acceptable limit of 75 mg/L and permissible limit of 200 mg/L of calcium in drinking water. The concentration of calcium in groundwater samples ranged from 13.60 to 141.50 mg/L. About 36% of samples were above the acceptable limit of BIS. Spatial distribution of calcium in groundwater of study area reveals that central part of study area has high calcium concentration (Fig. 2d). Similar results were also obtained for groundwater of Greater Noida *i.e.* concentration of calcium ranged from 10.91-135.69 mg/L [42].

**Magnesium:** A standard value prescribed by BIS is 30 mg/L (acceptable limit) and 100 mg/L (permissible limit) of magnesium concentration in drinking water. The concentration of magnesium in groundwater samples ranged from 33.36 to 116.6 mg/L. All the samples have magnesium concentration above the acceptable limit of 30 mg/L. Contour of magnesium in groundwater of study area shows a relatively higher concentration in south-east part and to some extent north-west part (Fig. 2e).

**Sodium and potassium:** The concentration of sodium and potassium in groundwater mainly depends upon the cation exchange of rock minerals. The taste impart by sodium to drinking water depends upon the type of associated anion. Chloride

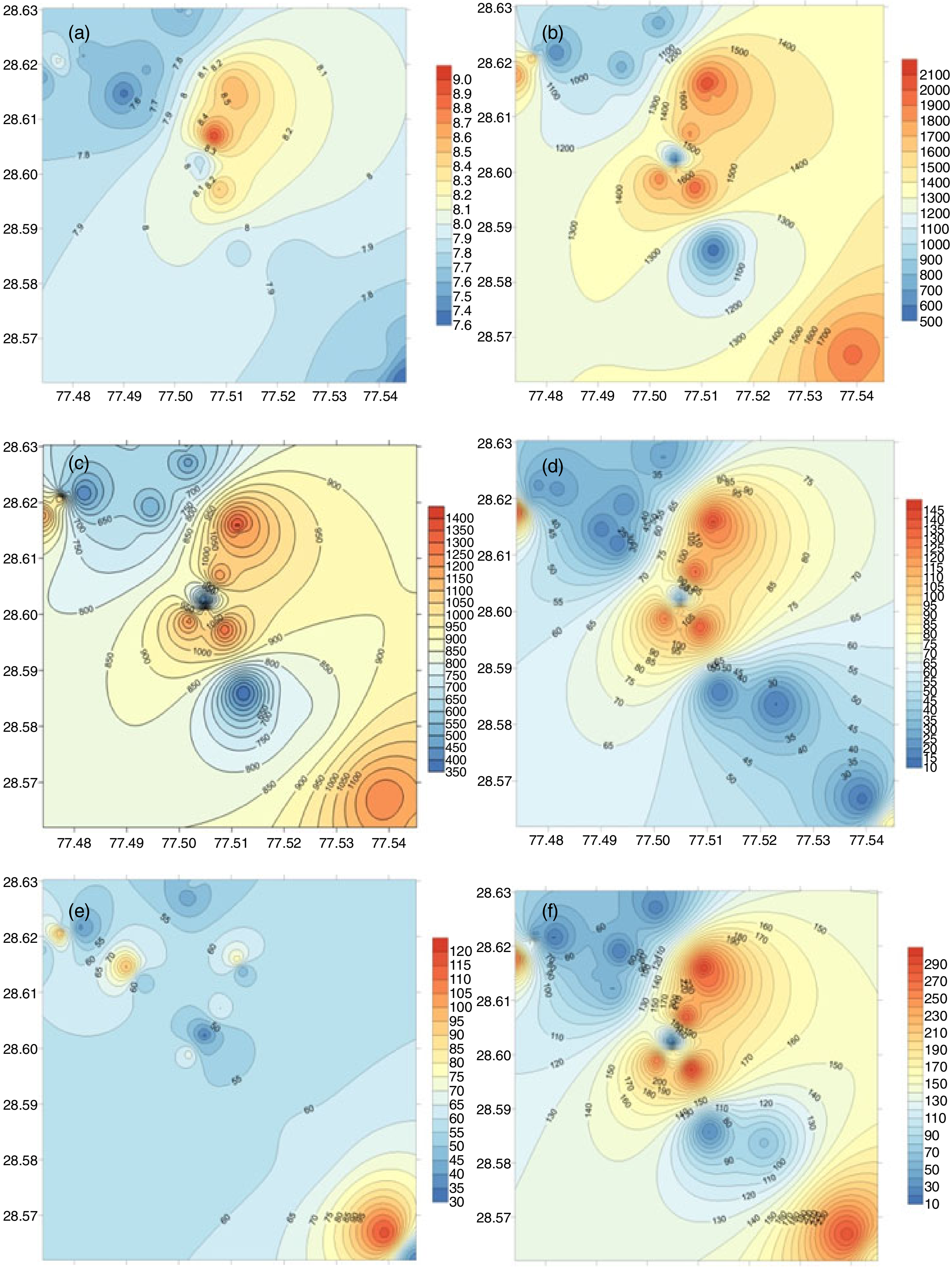


Fig. 2. Spatial distribution maps of selected hydro-parameters in groundwater samples (a) pH distribution, (b) EC distribution, (c) TDS distribution, (d) calcium distribution, (e) magnesium distribution and (f) chloride distribution

ions have higher tendency to associate with alkali metals (Na & K) than alkaline metals (Ca & Mg). Among the alkalies, the sodium ion concentration in groundwater samples of study area was found 6.93-234.0 mg/L (min.-max.) with a mean value of 118.10 mg/L. Around 18 % of samples exceed the standard limit of WHO [41] for sodium (200 mg/L) and the potassium concentration in groundwater sample ranged from 4.97 to 51.0 mg/L.

**Chloride:** Chloride is naturally present in groundwater with alkali metals ($Na^+$ & $K^+$) and alkaline earth metals ($Ca^{2+}$ & $Mg^{2+}$). Taste of water depends upon the concentration of these chlorides compounds in water. BIS prescribed 250 mg/L as an acceptable limit of chloride in drinking water. The analyzed range of chloride in groundwater samples of study area was from 9.8 to 298.0 mg/L. Results showed that samples collected from villages Achheja, Dujana, Badalpur, Bisrakh road and before Dhoom Manikpur have chloride concentration higher than the acceptable limit of BIS. Contour map of chloride shows the similar type of distribution pattern as calcium contour (Fig. 2f). A similar type of distribution pattern indicates the same source for calcium and chloride in groundwater. It was reported by Singh and Hussain [42] that 89 % of groundwater samples in Greater Noida region have chloride concentration within the acceptable limit of BIS in year 2016.

**Fluoride:** Fluoride concentration in groundwater depends upon the geology of that area. Disintegration of rocks and dissolution of fluoride rich menerals are the major sources of fluoride in groundwater. Long time intake of fluoride rich water causes various types of teeth and bones disorders. BIS sets the 1 mg/L (acceptable limit) and 1.5 mg/L (permissible limit) for fluoride in drinking water. Fluoride values in ground-water samples varied from 0.171 to 1.31 mg/L. All the samples were within the permissible limit of fluoride 1.5 mg/L and 91 % of the samples showed fluoride values below the acceptable limit of 1.0 mg/L. The current result is in close agreement with the previous result of Greater Noida region where 89 % of groundwater samples have fluoride concentration below 1.0 mg/L [42].

**Nitrate:** The main source of nitrate in groundwater is anthropological activities in the area. The nitrate concentration in groundwater samples ranged from 41 to 433 mg/L with a mean of 196.96 mg/L. Around 95.4% of groundwater samples have nitrate concentration above the standard limit of 45 mg/L (BIS). The residents of the study area used septic tanks instead of piped sewer system for the removal of sewage of house. The leakage of nitrogenous wastes from these tanks can contaminate ground-water with nitrate. An extensive use of nitrogeneous fertilizers in agriculture is also responsible for high concentration of nitrate in water.

**Sulfate:** The source of sulfate in groundwater can be natural or anthropological. Presence of excess of sulfates in drinking water imparts an unpleasent taste and can cause gastrointestinal disorders. The prescribed range of sulfate in drinking water is 200-400 mg/L [36]. Sulfate concentration in groundwater samples ranged from 1.91 to 298 mg/L and 23 % of samples exceeded the acceptable limit of sulfate concentration prescribed by BIS [36].

**Water quality index:** In present study, water quality indices of groundwater samples were calculated by selecting 10 parameters *viz*. pH, $Ca^{2+}$, $Mg^{2+}$, TH, $Cl^-$, $F^-$, $SO_4^{2-}$, $NO_3^-$, TDS and turbidity. Drinking water quality standards of BIS [36] were used for standardization of parameters. Finally by aggregating sub-indices for individual parameter, overall water quality index was calculated for each sample. By comparing the water quality index of each sample with standard water quality rating, the characterstic quality of groundwater was obtained. Water quality index of the collected groundwater samples was calculated by three methods to analyze the potability of water. The values of water quality indices calculated by three different methods are given in Table-5. Water quality indices of indivi-

TABLE-5
WQI VALUES OF INDIVIDUAL SAMPLES CALCULATED BY DIFFERENT METHODS AND THEIR SUITABILITY FOR DRINKING PURPOSE

| Samples No. | WAWQI | Water quality status as WAWQI method | GWQI | Water quality status as GWQI method | CCMEWQI | Water quality status as CCME WQI method |
|---|---|---|---|---|---|---|
| S1 | 2162 | Unsuitable | 662 | Unsuitable | 31 | Poor |
| S2 | 1950 | Unsuitable | 605 | Unsuitable | 37 | Poor |
| S3 | 290 | Unsuitable | 232 | Very Poor | 48 | Marginal |
| S4 | 100 | Very Poor | 100 | Good | 73 | Fair |
| S5 | 62 | Poor | 167 | Poor | 53 | Marginal |
| S6 | 83 | Very Poor | 185 | Poor | 29 | Poor |
| S7 | 170 | Unsuitable | 193 | Poor | 49 | Marginal |
| S8 | 79 | Very Poor | 123 | Poor | 71 | Fair |
| S9 | 124 | Unsuitable | 183 | Poor | 37 | Poor |
| S10 | 1302 | Unsuitable | 550 | Unsuitable | 38 | Poor |
| S11 | 41 | Good | 139 | Poor | 61 | Marginal |
| S12 | 127 | Unsuitable | 148 | Poor | 61 | Marginal |
| S13 | 36 | Good | 124 | Poor | 68 | Fair |
| S14 | 659 | Unsuitable | 320 | Unsuitable | 44 | Poor |
| S15 | 78 | Very Poor | 133 | Poor | 62 | Fair |
| S16 | 40 | Good | 114 | Poor | 71 | Fair |
| S17 | 82 | Very Poor | 151 | Poor | 61 | Marginal |
| S18 | 244 | Unsuitable | 133 | Poor | 55 | Marginal |
| S19 | 51 | Poor | 151 | Poor | 30 | Poor |
| S20 | 44 | Good | 161 | Poor | 30 | Poor |
| S21 | 94 | Very Poor | 146 | Poor | 32 | Poor |
| S22 | 94 | Very Poor | 197 | Poor | 29 | Poor |

dual sample shows a variation of quality of water from good to unfit.

The WQI values calculated from WAWQI method ranged from 36 to 2162. Around 82 % of groundwater samples came under poor to unsuitable type of quality of water. Nine samples (41 %) collected from villages Badhpura, Dhoom Manikpur, Dairy Maccha, Khera Dharampura, Bisrakh road, Duryai, Dujana and Badalpur were unsuitable for drinking (Fig. 3). Spatial distribution of WAWQI in study area shows that samples S1 & S2 collected from the south-east part of study area had exceptionally high WQI. These samples were taken from village Badhpura and Dhoom Manikpur (Fig. 4). Nearly 18 % of groundwater samples showed good water quality. Similar types of results were obtained from GWQI method. In this indexing method, GWQI value above 300 signifies that water is unsuitable for drinking. The water quality index calculated from GWQI method ranged from 100 to 662. Around 95 % of samples have poor to unsuitable quality of water. The GWQI values of sample S1, S2, S10 and S14 were above 300 *i.e.* unfit for drinking (Fig. 5). These values are fairly in agreement with the previous method. Only one sample S4 collected from village Sadopur has good water quality in GWQI method (Fig. 6). According to CCMEWQI, 77 % of samples came under poor to marginal type of water quality. Rest of the samples has fair type of water quality (Fig. 7). Lighter points on contour map of CCME WQI shows a poor water quality and darker points indicate a fair type of water quality (Fig. 8). Distribution pattern of CCME WQI in study area reflects that groundwater of central, south-east and north-west part have poor water quality. Three groundwater samples (S14-S16) were taken from village Duryai (agricultural area) but only water quality of sample S14 is unsuitable for drinking, while rest of the samples have good water quality. Distribution map of water quality index shows that

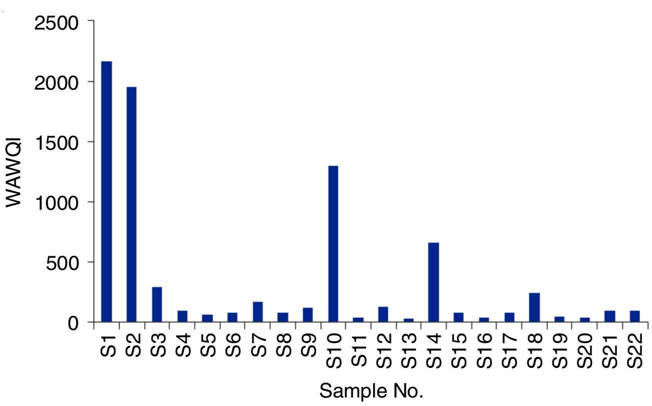


Fig. 3. Water quality index of groundwater samples using WAWQI method

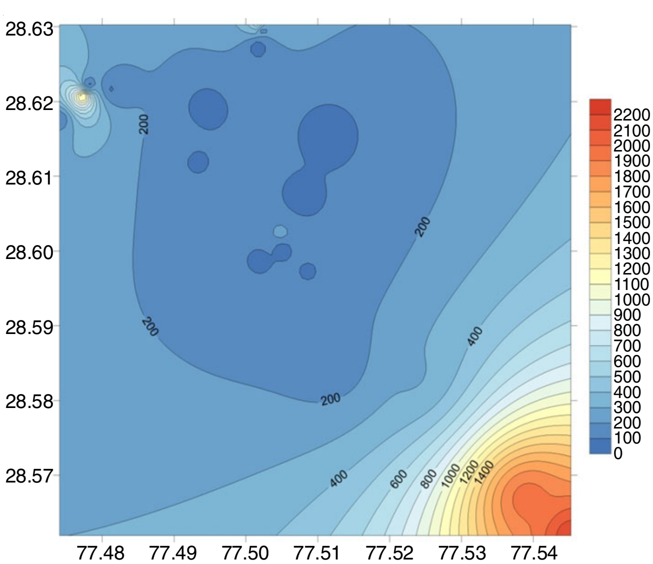


Fig. 4. Contour map of weighted arithmetic water quality index (WAWQI) of groundwater samples in study area

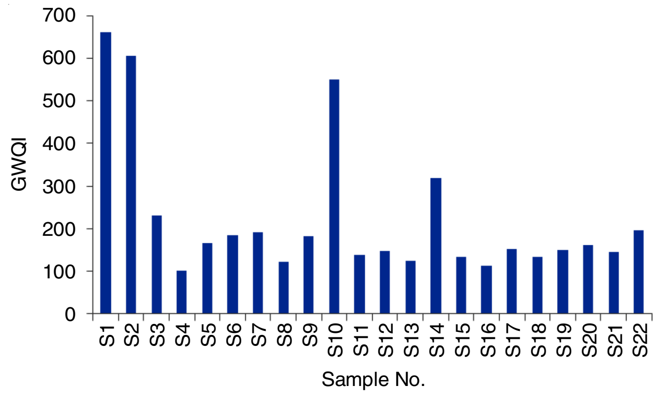


Fig. 5. Water quality index of groundwater samples using GWQI method

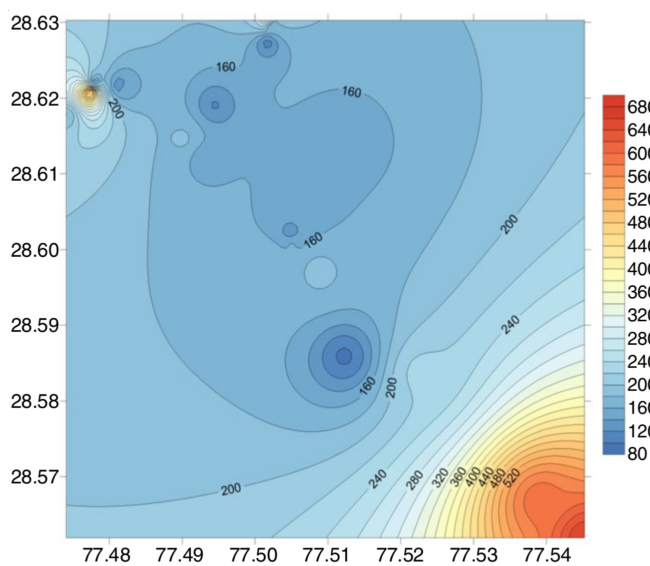


Fig. 6. Contour map of ground water quality index (GWQI) of groundwater samples in study area

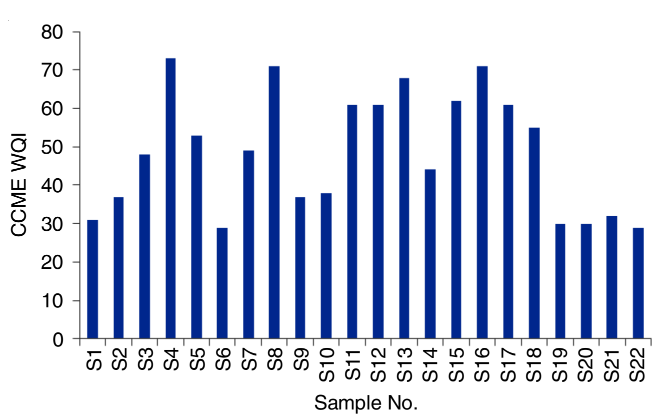


Fig. 7. Water quality index of groundwater samples using CCME WQI method

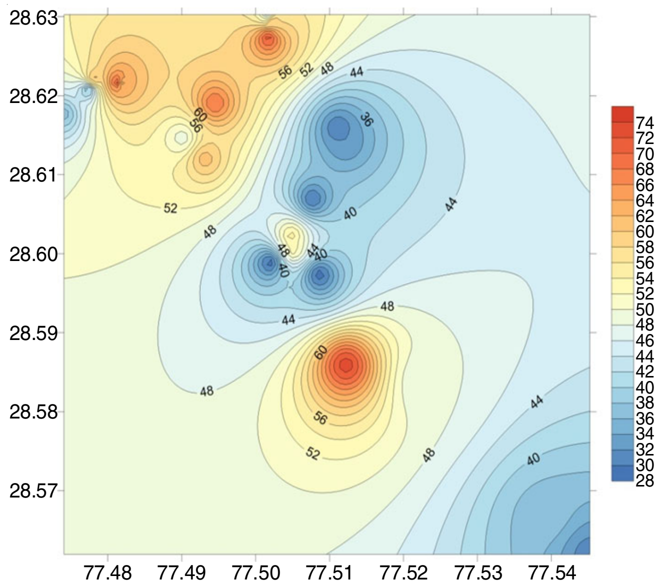


Fig. 8. Contour map of Canadian Council of Ministers of the Environment water quality index (CCME WQI) of groundwater samples in study area

groundwater of south-east part of study area was contaminated and not fit for drinking. The samples having poor to unfit type of water quality were distributed among the agricultural, industrial and residential areas. Based on the classification of WQI, it is concluded that groundwater of most of the sampling sites were not fit for drinking.

**Hydrogeochemical facies:** The relation between major cations and anions was evaluated by plotting the concentration of cations and anions ($Ca^{2+}$, $Mg^{2+}$, $Na^{+}$, $K^{+}$, $CO_3^{2-}$, $HCO_3^{-}$, $SO_4^{2-}$ and $Cl^{-}$) in milliequivalents per liter on piper trilinear diagram [44]. A piper diagram (Fig. 9) of groundwater samples explains the association and variation among different kinds of groundwater in the study area. The diamond field of piper plot is divided into four sub-fields: (1) $Ca^{2+}$-$Mg^{2+}$- $Cl^{-}$-$SO_4^{2-}$, (2) $Na^{+}$-$K^{+}$-$Cl^{-}$-$SO_4^{2-}$, (3) $Na^{+}$-$K^{+}$-$HCO_3^{-}$, and (4) $Ca^{2+}$-$Mg^{2+}$-$HCO_3^{-}$. Around 50 % of water samples come into the $Ca^{2+}$-$Mg^{2+}$-$HCO_3^{-}$ sub-field, 36.4% comes in $Ca^{2+}$-$Mg^{2+}$- $Cl^{-}$-$SO_4^{2-}$ sub-field and remaining 13.6 % comes under $Na^{+}$-$K^{+}$-$HCO_3^{-}$ sub-field. The sub-field $Ca^{2+}$-$Mg^{2+}$-$Cl^{-}$-$SO_4^{2-}$ contains most of those samples, which have high value of TDS and EC. In 86.4 % of samples alkaline earth metals ($Ca^{2+}$ & $Mg^{2+}$) exceeded alkali metal ($Na^{+}$

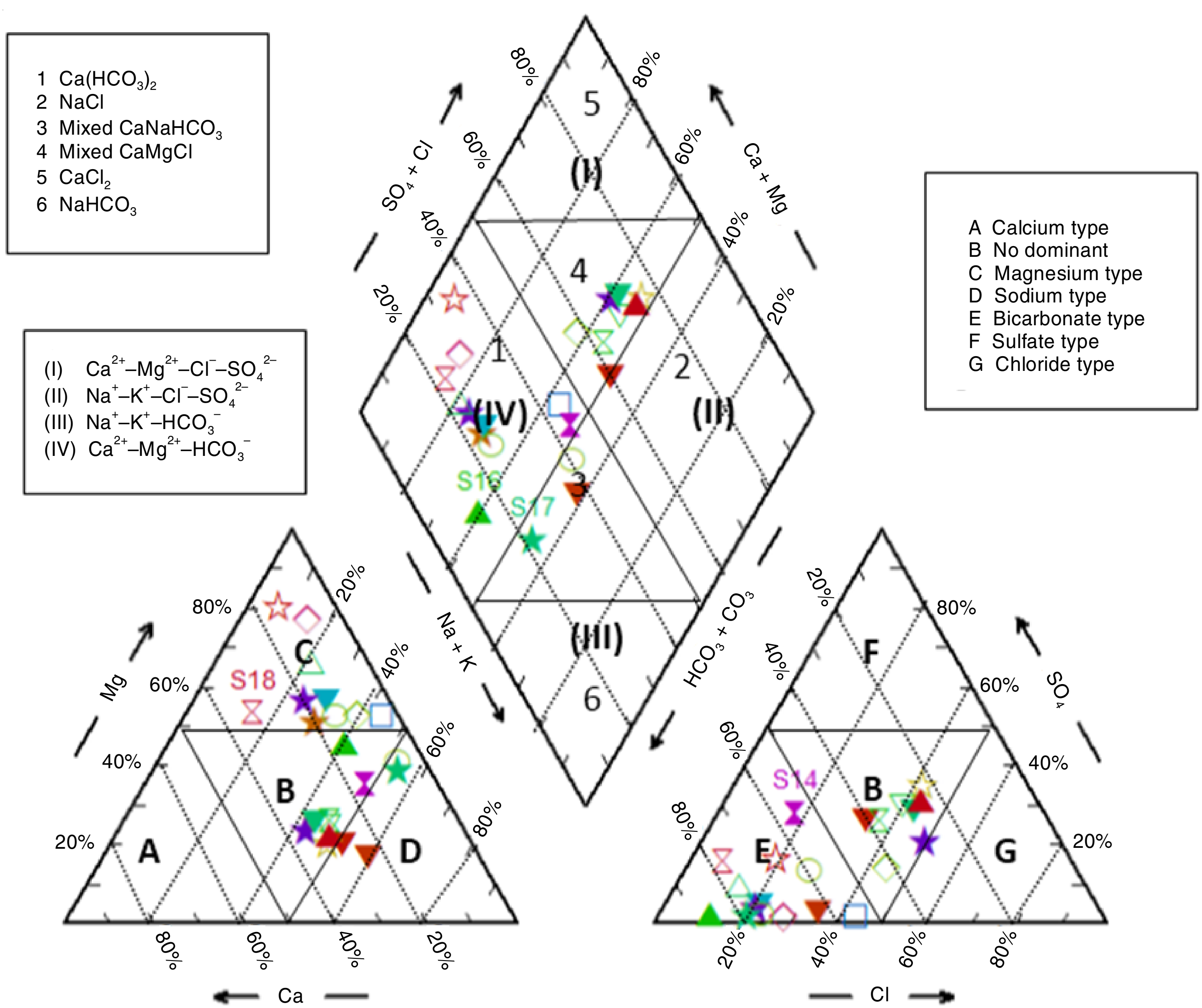


Fig. 9. Piper trilinear diagram of groundwater samples

TABLE-6
CHARACTERIZATION OF GROUNDWATER SAMPLES ON THE BASIS OF PIPER TRILINEAR DIAGRAM

| Subfields of the diamond | Characteristics of corresponding subfields of diamond-shaped field | Number of samples in the category | Percentage of samples in the category |
|---|---|---|---|
| 1 | Alkaline earths (Ca + Mg) exceed alkalis (Na + K) | 19 | 86.4 |
| 2 | Alkalis exceed alkaline earths | 3 | 13.6 |
| 3 | Weak acids ($CO_3$ + $HCO_3$) exceed strong acids ($SO_4$ + Cl) | 14 | 63.6 |
| 4 | Strong acids exceed weak acids | 8 | 36.4 |
| 5 | Magnesium-bicarbonate type | 11 | 50 |
| 6 | Calcium-chloride type | 0 | 0 |
| 7 | Sodium-chloride type | 0 | 0 |
| 8 | Sodium-bicarbonate type | 0 | 0 |
| 9 | Mixed type (no cation-anion exceed 50 %) | 11 | 50.0 |

& $K^+$) and in 13.6 % of samples alkali metals ($Na^+$ & $K^+$) were higher than alkaline earth metal ($Ca^{2+}$ & $Mg^{2+}$). In 63.6% of samples weak acids ($CO_3^{2-}$ + $HCO_3^-$) dominated over strong acids ($SO_4^{2-}$ + $Cl^-$). Strong acids ($SO_4^{2-}$ + $Cl^-$) were higher than weak acids ($CO_3^{2-}$ + $HCO_3^-$) in 36.4 % of samples (Table-6). For $Cl^-$, $SO_4^{2-}$ and $HCO_3^-$ concentrations, the groundwater sources can be classified into normal chloride (less than 15 meq/L), normal sulfate (less than 6 meq/L) and normal bicarbonate (2-7 meq/L) water types [45]. In current study, 86.4 % of groundwater samples were of normal bicarbonate type, 95.5 % of samples were of normal sulphate type and all the samples showed normal chloride type quality of water.

## Conclusion

The groundwater quality of Gautam Budh Nagar district of India, was evaluated in terms of water quality indices on the basis of chemical composition of water. The pH of samples ranged from 7.31 to 8.97 with a mean of 7.88, which indicates slightly alkaline nature of water. All the samples exceeded the acceptable limit of BIS for magnesium and total hardness. Around 95 % of samples have concentration of nitrate higher than the standard limit of nitrate given by BIS (45 mg/L). By studying hydrochemical characterstics of groundwater samples, it is concluded that most of the samples were beyond the acceptable limit of turbidity, TDS, calcium, chloride and sulfate. However, fluoride concentration was well below the acceptable limit of BIS in all the samples except samples S6 and S18. Piper plot shows that $Ca^{2+}$-$Mg^{2+}$-$HCO_3^-$, $Ca^{2+}$-$Mg^{2+}$-$Cl^-$-$SO_4^{2-}$ and $Na^+$-$K^+$-$HCO_3^-$ were the major hydrochemical facies of groundwater of study area. Calcium & magnesium were major cations in 86.4 % of samples and carbonate & bicarbonate were major anions in 63.6 % of samples. Water quality indices of groundwater samples indicate that 82 % (WAWQI), 95 % (GWQI) and 77 % (CCME WQI) of samples have poor to unsuitable type of water. Groundwater samples of almost all the sampling sites were contaminated and not good for drinking. Spatial distribution of water quality indices shows that south-east part of the study area has unsuitable type of quality of groundwater. Proper management for the disposal of domestic and agricultural wastes is required to improve the quality of water.

## CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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