Research Article

Hydrogeochemical assessment of groundwater quality in parts of the Hindon River basin, Ghaziabad, India: implications for domestic and irrigation purposes

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Abstract

The present study confers the hydrogeochemical characteristics and groundwater quality assessment for drinking and irrigational purposes. Most of the population depends on groundwater for their daily needs especially for drinking, irrigation, and industrial purposes. For this reason, total seventy-two groundwater samples have been collected from different parts of Ghaziabad district for the pre- and post-monsoon in the year 2016 and analyzed for water quality parameters such as pH, electrical conductivity, total dissolved solids, total hardness, bicarbonate (HCO_3^-), carbonate (CO_3^{2-}), chloride (Cl^-), sulphate (SO_4^{2-}), fluoride (F^-), calcium (Ca^{2+}), magnesium (Mg^{2+}), sodium (Na^+), and potassium (K^+). Results show that the water samples of the study area are generally hard to very hard and slightly acidic to alkaline in nature. Results also suggest that chloride (Cl^-) ions dominate over SO_4^{2-} ions, whereas HCO_3^- ions dominate over Cl^- and SO_4^{2-} in the studied groundwater samples during the pre- and post-monsoon periods. The Piper trilinear diagram of groundwater shows that dominant facies is Na^+–HCO_3^- type in both the monsoon periods. The nitrate concentration in the groundwater samples varies from 22 to 293 mg/l in the pre-monsoon, of which 83% of groundwater samples are not recommended for drinking with reference to the concentration of nitrate. Base-exchange indices classified 89% and 11% of the water sources as the Na-HCO_3 type and Na-SO_4 during the pre- and post-monsoon seasons, respectively. According to the meteoric genesis indices, 89% and 11% of the water sources as shallow meteoric water percolation and deep meteoric water percolation type during the pre- and post-monsoon periods, respectively. Furthermore, most of the groundwater samples are found mainly influenced by rock dominance according to Gibbs diagram plots.

Keywords Hydrogeochemical · Water quality · Industrial pollution · Hindon River · Ghaziabad

1 Introduction

Groundwater forms an essential component of the hydrological cycle [1]. It is a ubiquitous resource of the blue planet which helps in the existence and survival of all spheres of life and also plays a pivotal role in industrial and agricultural activities. In recent times, huge population growth, rapid urbanization, increased industrial and agricultural activities all over the world show a tremendous increase in freshwater demand [2, 3]. Due to an inadequate supply of fresh surface water, most of the people in arid and semi-arid regions of India are depending primarily on groundwater for their daily needs and irrigation usages. On the other hand, groundwater quality has been constantly deteriorating and becoming a shrewd concern since last few decades [4–10]. In India, urban runoffs and sewage disposals in river catchments pose a challenge for the maintenance of river water quality [11, 12]. This has been degrading groundwater geochemistry because rivers carry the toxic elements and chemical effluents discharged from various transport pathways. These include industrial wastes, unsystematic use of fertilizers and pesticides in

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agricultural practices without a proper understanding of the physicochemical characteristics of soils and groundwater and without following any appropriate remedial measures [13]. Further, the groundwater quality is influenced by several other factors like rainfall, topography relief, mineral dissolution, mineral solubility, ion exchange, oxidation, reduction, and mineralogy of the watersheds and aquifer's structure and geology [3, 14–16]. Therefore, it is most important to monitor the quality of water resources, particularly groundwater, in arid and semi-arid regions in India which is considered as a primary source for drinking and irrigation purposes.

There are several studies that have been conducted on groundwater quality assessment in different parts of India and many parts of the world with respect to drinking and irrigation [17–27]. Kaur et al. [17] studied the quality of groundwater for drinking and irrigation purposes in the Malwa region, Punjab that indicates poor water quality of the region. Tamma et al. [18] carried out a hydrochemical assessment of groundwater in Jalandhar district. Ravi et al. [19] have studied geochemistry of groundwater quality and its evaluation in Karnataka. On the other hand, in a recent study conducted by Khan and Umar [27] in central Ganga plain suggest that groundwater is contaminated due to indiscriminate disposal of coal fly. They also found the presence of arsenic mineral phases in agricultural soil samples due to the untreated release of effluents from a thermal power plant in the studied area.

The present study area falls in the Ghaziabad District (Uttar Pradesh, India) located along the Hindon River. The Ghaziabad District is one of the fastest growing industrial areas having an important role in the socio-economic development of state Uttar Pradesh [12]. Industries manufacturing paint, varnish, electroplated materials, pharmaceuticals, liquor, etc. are located within the district of Ghaziabad. Presently, Ghaziabad is witnessing rapid growth in terms of industrialization and urbanization as well as a marked increase in various municipal and agricultural activities [28]. The Hindon River, a major source of groundwater recharge, receives huge volumes of wastewater every day from the catchment areas in Ghaziabad. Such wastewater from the industries, urban households and agricultural activities are a major pollutant of the groundwater quality. Thus, the rapid industrialization and urbanization in Ghaziabad have posed a challenge to the environment in general and the Hindon River in particular; causing deterioration of the water quality at an alarming rate [29]. Therefore, knowledge of hydrogeochemistry of the groundwater is very essential to evaluate the water quality for drinking, irrigation and other needs. The study of groundwater quality for Ghaziabad district is inadequate. Furthermore, the aquifers in the alluvial region of the densely populated northern Indo-Gangetic plains are prone to anthropogenic contamination from intensive agricultural and industrial activities. This is one of the main reasons to select Ghaziabad district to evaluate the groundwater quality issues with the main objective to assess the groundwater quality for drinking and irrigation purposes.

2 Materials and methods

2.1 Study area

The Hindon River, a tributary of the River Yamuna, originating from Saharanpur District traverses Muzaffarnagar, Meerut, Baghpat, Ghaziabad and Gautam Budh Nagar districts of Uttar Pradesh in northern India. It lies between the latitudes 28°30′ to 30°15′N and longitudes 77°20′ to 77°50′E. It has an estimated basin area of about 7000 sq. km. It is largely composed of Pleistocene and Quaternary alluvium represented by sand, clay, kankar and reh. In the study area, the strata consist mainly of sandy soil. The soil is fertile and loamy. The depth of sub soil water table in this area is about 10–15 m below the ground level and the seasonal variation is about 5 m [30]. During the monsoon period (July to September), the study area witnesses the maximum rainfall. It experiences the hottest weather during the month of June (average temperature: 40 °C) and coldest during the month of January (average temperature: 5 °C). The average annual rainfall of the study area during monsoon is 901 mm, whereas winter rainfalls are almost negligible.

On the basis of exploratory drilling carried out in the area three-tier aquifer systems have been identified down to a depth of 450 mbgl [30]. The first aquifer system extends down to a depth of 125 mbgl and it extends down to 200 mbgl in the north part of the district. The thickness of aquifer decreases in the western part of the district and depth of bedrock is shallow. Second aquifer system exists in the depth range of 170–350 mbgl. The aquifer is medium- to fine-grained sand with occasional coarse-grained sand. The third aquifer system occurs below 350 mbgl and continues down to depth explored of 450 mbgl. The upper aquifer is the main source of water supply to the dug wells and shallow tube wells.

2.2 Collection of water samples

A total of seventy-two groundwater samples have been collected along with their GPS locations Fig. 1 in the pre- (April) and post-monsoon (December) from the study area (2016). All the samples were collected in new prewashed polyethylene bottles of 1 litre capacity for laboratory analyses from hand pumps, bore-wells. The sampling

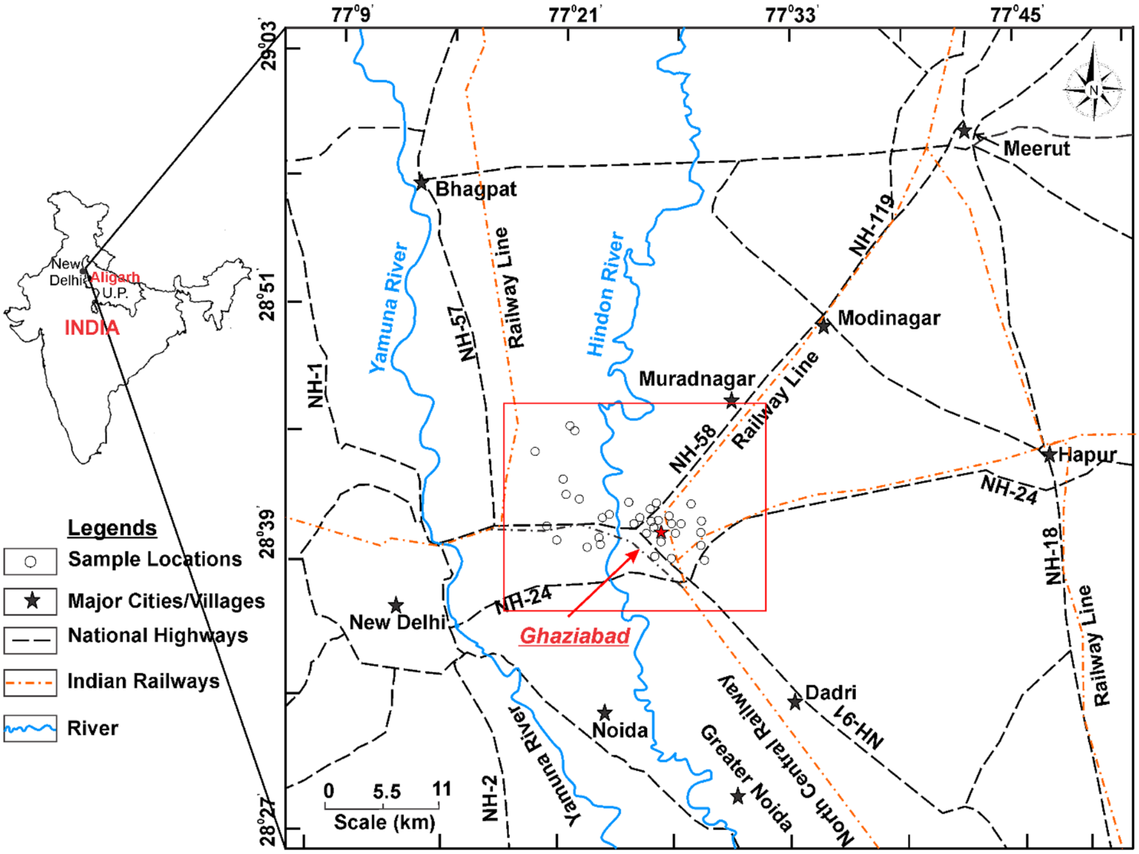

Fig. 1 Location map of the study area

bottles were filtered in the laboratory but not acidified. For the concentration of major cations (K^+, Na^+, Ca^{2+}, Mg^{2+}) and major anions (HCO_3^-, CO_3^{2-}, NO_3^-, Cl^-, F^-, SO_4^{2-}), the water analysis were carried out at Geochemistry Laboratory, Department of Geology, Aligarh Muslim University Aligarh; following the standard water examination methods [31]. The parameters such as hydrogen ion concentration (pH) and electrical conductivity (EC) were measured by pH and EC meter (HANNA HI98107, HI96304). Total dissolved solids (TDS) were calculated by multiplying Electrical Conductivity (EC) with a conversion factor from 0.55 to 0.75 depending on the relative concentration of ions [32, 33]. Total hardness and calcium concentration were obtained by titration method using EDTA while chloride concentration was obtained by argentometric titration using standard silver nitrate as a reagent. Magnesium concentration was calculated by the difference in hardness and calcium. The concentration of carbonate and bicarbonate were analyzed by standard HCL titration method. Sodium (Na^+) and potassium (K^+) were measured by flame emission photometer (EIL, PAT NO- 712700 REG. DES. NO-866150); sulfate, nitrate, and fluoride were determined by spectrophotometric technique (SHIMADZU CORP. 07410, SERIAL NO. A114549). The analytical results checked using charge-balance error for major ionic contents, the accuracy of these standards was within ± 10%. The obtained results have been compared by the World Health Organization [34] and the Bureau of Indian Standard [35]. The physicochemical characteristics of water samples were determined following standard protocol by [31].

3 Results and discussion

3.1 Physicochemical analysis

Analytical results for the various parameters are presented in Tables 1 and 2 and the results are compared with WHO (2011) and BIS (2012) water quality standards in Table 3. The pH value of groundwater varies from 7.5 to 8.8 and from 6.4 to 7.9 during the pre- and post-monsoon seasons (see Table 1). This reveals that the analyzed water samples are alkaline in nature during the pre-monsoon while water samples are slightly acidic to alkaline during the post-monsoon. This might be probably due to the improper irrigation process, anthropogenic activities like sewage disposals and leaching of dissolved constituents in groundwater resources.

Table 1 Statistical summary of groundwater chemistry in the pre- and post-monsoon 2016 (all values in mg/l except pH and EC)

Parameter	pH	EC	TDS	TH	CO_3^{2-}	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	F^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Pre Monsoon (2016) (n = 36)														
Minimum	7.50	300.00	192.00	140.00	52.00	130.00	52.11	21.59	36.92	0.00	14.43	22.39	24.00	6.00
Maximum	8.80	3600.00	2304.00	568.00	156.00	598.00	215.74	292.66	1079.20	1.50	68.94	105.26	584.00	37.00
Mean	8.25	1258.33	805.33	271.44	91.00	301.53	94.36	90.03	198.33	0.56	31.17	47.21	183.89	15.17
Std. Deviation	0.29	647.81	414.60	89.53	30.95	117.51	36.56	53.43	207.60	0.39	12.17	19.07	124.73	6.06
Skewness	−0.01	1.56	1.56	1.55	0.36	0.79	1.82	1.78	2.82	0.75	1.26	1.38	1.54	1.60
Kurtosis	−0.08	3.90	3.90	3.02	−0.80	0.38	3.94	4.48	8.98	−0.16	1.76	2.01	3.17	3.89
Post Monsoon (2016) (n = 36)														
Minimum	6.40	300.00	192.00	156.00	BDL	195.00	16.52	0.00	31.24	0.00	22.44	3.90	36.00	7.00
Maximum	7.90	3500.	2240.00	656.00	BDL	780.00	393.82	68.90	1025.24	1.17	195.59	78.94	592.00	30.00
Mean	7.26	1366.67	874.67	327.67	BDL	505.19	78.44	13.36	205.82	0.43	65.95	39.83	188.00	16.44
Std. Deviation	0.34	714.53	457.30	125.18	BDL	131.12	70.58	17.26	198.52	0.31	43.56	15.47	126.72	5.89
Skewness	−0.15	1.07	1.07	1.25	BDL	−0.21	2.99	2.37	2.47	0.87	1.42	0.39	1.48	0.56
Kurtosis	−0.10	1.48	1.48	1.00	BDL	−0.24	10.65	5.25	7.62	0.39	1.20	0.94	2.84	0.05

The unit of EC in µS/cm

Table 2 Correlation coefficients among various water quality parameters

	pH	EC	TDS	TH	HCO_3^-	SO_4^{2-}	NO_3^-	Cl^-	Ca^{2+}	Mg^{2+}	Na^+	K^+
Pre Monsoon (2016)												
pH	1.00											
EC	−0.17	1.00										
TDS	−0.17	1.00	1.00									
TH	−0.32	0.40	0.40	1.00								
HCO_3^-	−0.50	0.16	0.16	0.16	1.00							
SO_4^{2-}	−0.33	0.23	0.23	0.26	0.15	1.00						
NO_3^-	−0.01	0.00	0.00	0.05	0.17	0.07	1.00					
Cl^-	−0.06	0.93	0.93	0.39	−0.10	0.08	−0.09	1.00				
Ca^{2+}	−0.11	0.34	0.34	0.51	−0.26	0.13	−0.14	0.50	1.00			
Mg^{2+}	−0.32	0.32	0.32	0.94	0.28	0.25	0.11	0.26	0.20	1.00		
Na^+	−0.18	0.95	0.95	0.35	0.17	0.30	−0.02	0.89	0.34	0.27	1.00	
K^+	−0.31	0.73	0.73	0.25	0.42	0.21	−0.14	0.61	0.15	0.23	0.71	1.00
Post Monsoon (2016)												
pH	1.00											
EC	−0.29	1.00										
TDS	−0.29	1.00	1.00									
TH	−0.28	0.47	0.47	1.00								
HCO_3^-	−0.47	0.33	0.33	0.05	1.00							
SO_4^{2-}	−0.08	0.56	0.56	0.54	−0.09	1.00						
NO_3^-	−0.05	0.22	0.22	0.35	0.28	−0.05	1.00					
Cl^-	−0.21	0.93	0.93	0.40	0.10	0.43	0.14	1.00				
Ca^{2+}	−0.10	0.50	0.50	0.86	−0.13	0.55	0.23	0.50	1.00			
Mg^{2+}	−0.39	0.07	0.07	0.50	0.31	0.13	0.28	−0.05	−0.01	1.00		
Na^+	−0.16	0.88	0.88	0.15	0.43	0.35	0.28	0.83	0.18	−0.02	1.00	
K^+	−0.39	0.79	0.79	0.23	0.41	0.55	−0.02	0.65	0.20	0.12	0.68	1.00

Electrical conductivity (EC) is the measure of a material able to allow the transport of electric charge; which is commonly measured in µS/cm. The permissible limit for EC of drinking water is ~ 1500 µS/cm. Water samples having higher contents of salts usually display higher values of EC. However, EC of the analyzed groundwater samples of the

Table 3 Range of concentration of various major ions in groundwater samples for this study and their comparison with B.I.S. (2012) and W.H.O. (2011) drinking water standards

Parameters	BIS (2012) (mg/l)		W.H.O. (2011) (mg/l)		Study area (mg/l)	
	Highest desirable level	Maximum permissible level	Highest desirable level	Maximum permissible level	Pre Monsoon (2016)	Post Monsoon (2016)
pH	6.5–8.5	6.5–9.5	7–8.5	9.2	8–9	6–8
TH	200	600	100	500	140–568	156–656
TDS	500	2000	600	1000	192–2304	192–2240
Ca^{2+}	75	200	75	200	14–69	22–196
Mg^{2+}	30	100	–	150	22–105	4–79
Na^{+}	–	–	–	200	24–584	36–592
Cl^{-}	250	1000	250	600	37–1079	31–1025
SO_4^{2-}	200	400	200	600	52–216	17–394
NO_3^{-}	45	NR	50	NR	22–293	0–69

studied area exhibits a wide variation. It ranges from 300 to 3600 µS/cm in the pre-monsoon and 300 to 3500 µS/cm during the post-monsoon Table 1. About 58% of the groundwater samples exceed the prescribed permissible limits (> 1000 µS/cm) of [34, 35] for both the pre- and post-monsoon seasons. Thus, the anomalously high values of EC in the samples may probably be due to the higher contents of salts.

Total dissolved solids (TDS) represents the measure of the total dissolved solids present in the water bodies. The TDS content ranges of groundwater samples from 192 to 2304 mg/l and 192 to 2240 mg/l during the pre- and post-monsoon seasons Table 1. Spatial examination of the pre-monsoon groundwater samples reveals that 78% of the samples have TDS values ranging between 192 and 1000 mg/l which falls under the freshwater category while 17% of the water samples have TDS values ranging from 1000 to 1500 mg/l suggesting that it is brackish in nature; and remaining 5% of the samples have TDS values (> 1500 mg/l) indicating that it is inappropriate for drinking owing to its high TDS contents. Likewise, groundwater samples of the post-monsoon season, 67% of samples bear TDS value less than 1000 mg/l suggesting that they are freshwater; TDS value in water samples (25%) varied from 1000 to 1500 mg/l; and the remaining samples (8%) have TDS values (> 1500 mg/l) indicating that it is incompatible for human health due to high TDS concentration.

The hardness value of the groundwater samples varies from 140 to 568 mg/l (avg. 278 mg/l) Table 1. We observed that the 22% groundwater samples collected during the pre-monsoon season have higher total hardness than the allowable limit for drinking purposes (> 300 mg/l). Therefore, in terms of total hardness, the samples fall in the category of hard to very hard. During the post-monsoon, the hardness values vary from 156 to 656 mg/l (avg. 324 mg/l), and 47% of the groundwater samples have total hardness values above the desirable limit. Nitrate ion content of the water samples ranges from 22 to 293 mg/L and 0 to 67 mg/l during the pre- and post-monsoon seasons, respectively Table 1. Out of 36 water samples, 30 groundwater samples have nitrate ion contents are afar the permissible limit (> 45 mg/l) of [34] for drinking purposes. The concentration of nitrate ions in excess of 45 mg/l in the drinking water has antagonistic effects on human health. It can commonly cause methemoglobinemia (generally known as "blue baby syndrome") in infants.

3.1.1 Chemical classification of groundwater samples

The groundwater samples have been classified based on Cl^{-}, SO_4^{2-} and HCO_3^{-} contents as normal chloride (< 15 meq/l), normal sulfate (< 6 meq/l) and normal bicarbonate (2–7 meq/l). Based on the [36] classification, the majority of the groundwater samples are found to be sulfate type followed by normal bicarbonate and normal chloride type during the pre-monsoon and post-monsoon seasons.

(a) Base-exchange indices (r_1)

The considered groundwater samples are further classified using base-exchange indices which have been calculated using the following equation [36, 37]:

$$r_1 = \frac{Na^{+} - Cl^{-}}{SO_4^{2-}}$$

where r_1 denotes the base-exchange index; Na^{+}, Cl^{-} and SO_4^{2-} concentrations are expressed in meq/l. A value of $r_1 < 1$, the groundwater source is of Na^{+}–SO_4^{2-} type, whereas a value of $r_1 > 1$ indicates the groundwater source is of Na^{+}–HCO_3^{-} type. According to the base-exchange indices (Fig. 2a), 11%, groundwater samples classify as Na^+–SO_4^{2-} type ($r_1 < 1$), whereas 89% samples are Na^+–HCO_3^- type ($r_1 > 1$) during the pre- and post-monsoon seasons.

(b) Meteoric genesis indices (r_2)

The groundwater sources can also be classified based on meteoric genesis indices which are calculated using the following equation [36, 37]:

$$r_2 = \frac{K^+ + Na^+ - Cl^-}{SO_4^{2-}}$$

where r_2 denotes meteoric genesis index; K^+, Na^+, Cl^-, and SO_4^{2-} concentrations are expressed in meq/l. If $r_2 < 1$, the groundwater sources is of deep meteoric water percolation while $r_2 > 1$ indicates that it is of shallow meteoric water percolation type. Based on the calculated r_2 values, 11% of groundwater samples are deep meteoric water percolation and 89% of the groundwater samples are shallow meteoric water percolation type during the pre- and post-monsoon seasons Fig. 2b.

3.1.2 Hydrogeochemical facies

Hydrogeochemical evolution of the groundwater samples has been ascertained using dissolved constituents (major cations and major anions) in piper trilinear diagram [38]. The piper trilinear diagram was used to evaluate the variation in hydrogeochemical facies. Piper diagram includes three fields i.e. two triangular fields and one diamond-shaped field. The value of cations and anions present in a percentage of meq/l on the left and right [38, 39]. After plotting points of cations and anions are extend to upper filed and where these points intersect indicates the water type with respect to Na^+, K^+, Ca^{2+}, Mg^{2+}, CO_3^{2-}, HCO_3^-, Cl^- and SO_4^{2-} ions. The most water samples in the study area fall in Na^+–HCO_3^- type and remaining samples also fall in the Na^+–Cl^-–SO_4^{2-} and Ca^{2+}–Mg^{2+}–HCO_3^- types in the pre- and post- monsoon seasons Fig. 3a, b. As per Piper diagram in which Na^+/K^+ cations and CO_3^{2-}/HCO_3^- are dominant anions in groundwater.

3.1.3 Gibbs diagram

Gibbs diagram is employed to understand the mechanisms that control the dissolved chemical constituents of groundwater in relation to aquifers which are divided into three distinct zones such as precipitated water, rock-water interaction and evaporation [40]. The TDS values are plotted against ratios of dominant cations (Na + K)/(Na + K+ Ca) and anions Cl/(Cl + HCO_3). In Gibbs diagram (Fig. 4a, b) during the pre- and post-monsoon analyzed samples dominantly fall in the rock-dominance field which indicates the interaction between the rock chemistry and the chemistry of groundwater. Further, a few samples also show the minor influence of evaporation which increases salinity by increasing Na and Cl with relation to increasing in TDS during both the seasons Fig. 4a, b.

3.1.4 Water quality criteria for irrigation purpose

The analytical data of the water samples from the study area have been plotted in the USSL diagram. The USSL diagram is proposed by [41] to assess the quality of irrigation water in which EC is taken as an index of sodium hazard. Taking ionic concentrations of sodium, calcium, and magnesium expressed in meq/l, the SAR is calculated using the following equation:

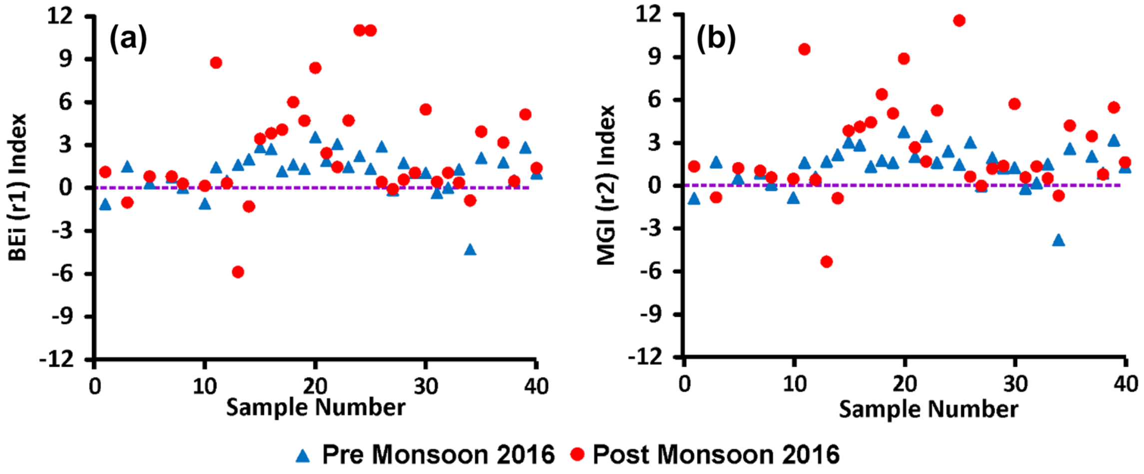

Fig. 2 **a** Base-exchange indices (r_1) and **b** meteoric genesis indices (r_2)

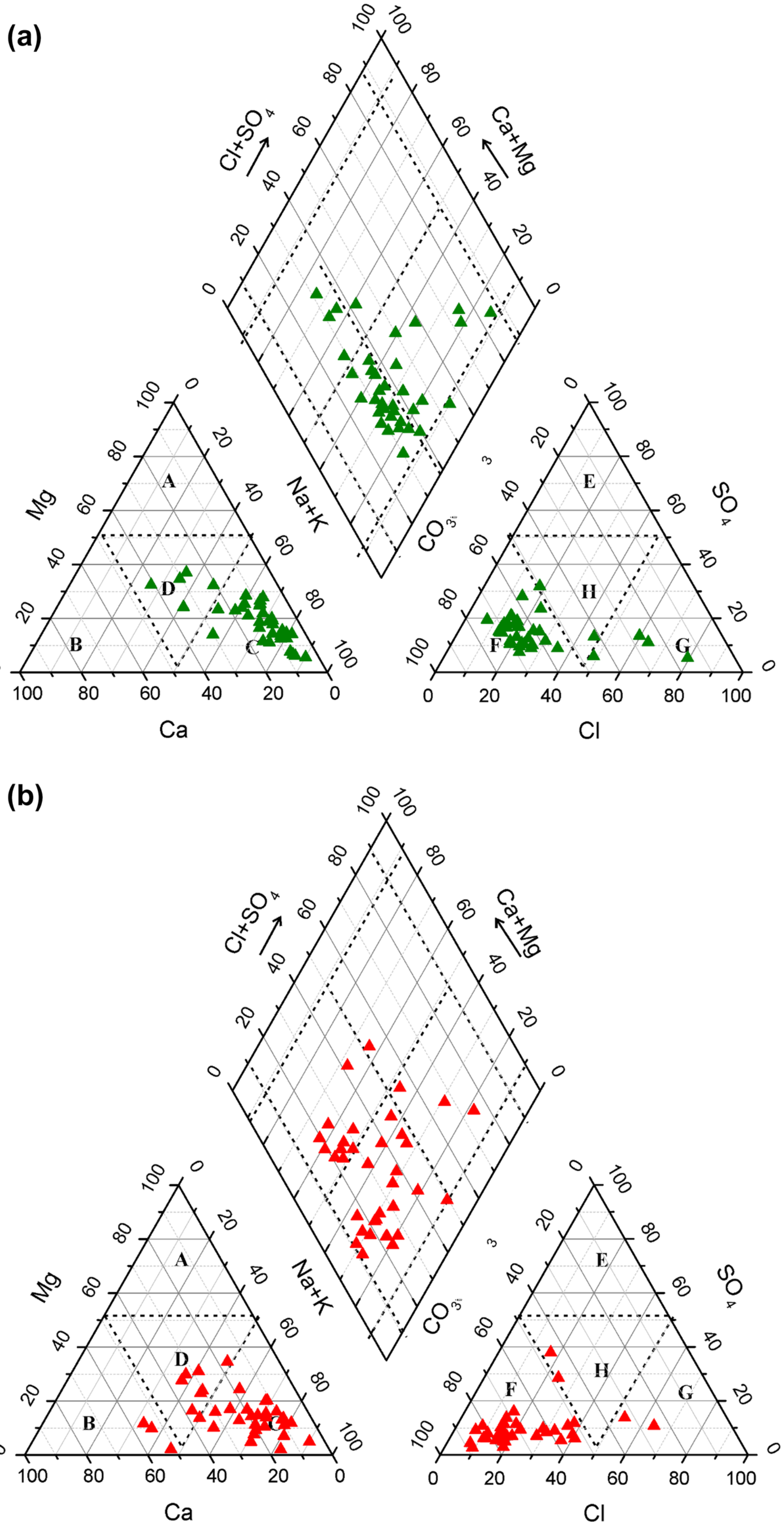

Fig. 3 Piper-trilinear diagram for **a** pre-monsoon, **b** post-monsoon

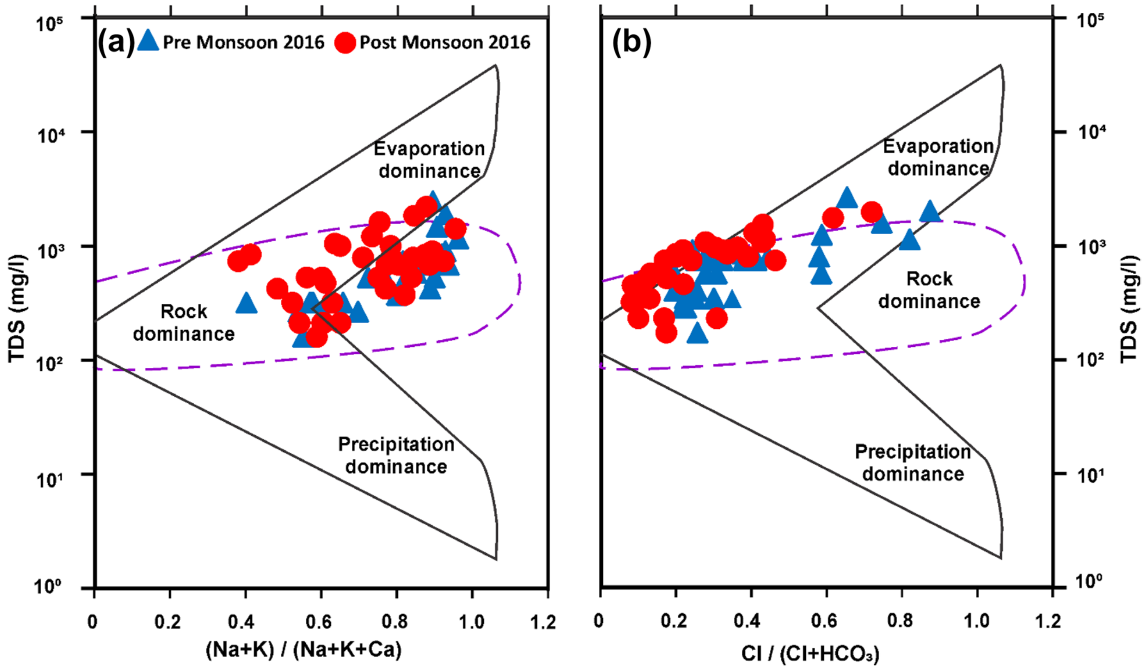

Fig. 4 Gibbs diagram for **a** cations and **b** anions

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

In the USSL diagram, most of the pre-monsoon samples falling in the C1S1, C2S1 fields (i.e. low to medium salinity with low sodium hazard) which are suitable for irrigation purpose, whereas few samples falling in the C3S2 field (high salinity with medium sodium hazard) are deemed unsuitable for irrigation purposes Fig. 5. Most of the post-monsoon samples fall in the fields of C1S1 and C2S1 indicating that they have low to medium salinity hazard and

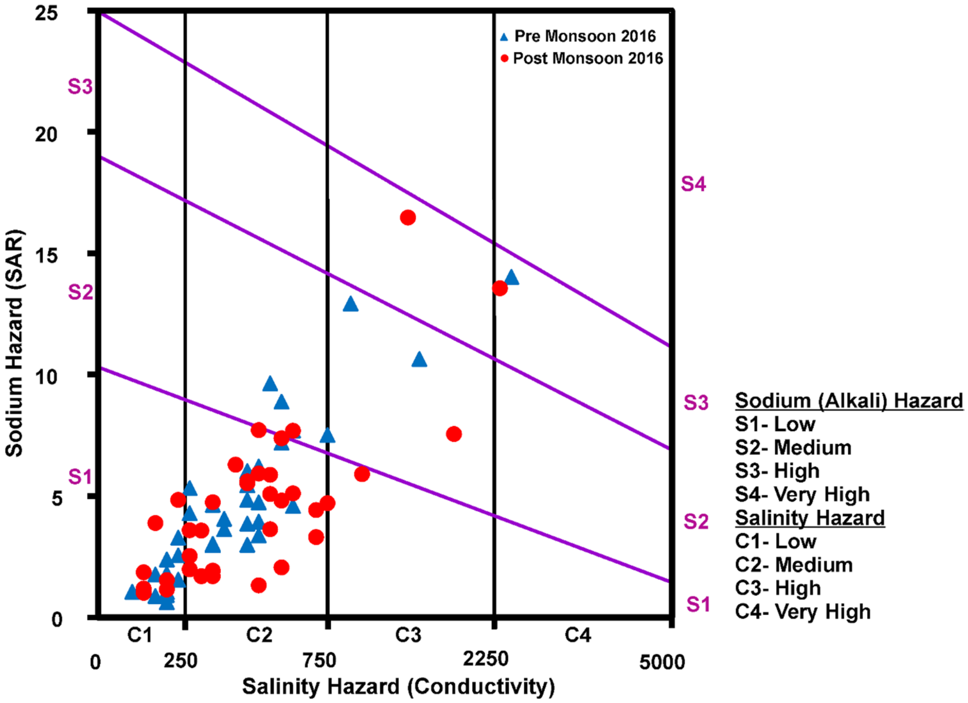

Fig. 5 US Salinity laboratory diagram (USSL)

low sodium hazard. This suggests that the post-monsoon water samples from the study area are also suitable for irrigation.

3.1.5 Comparison of the abundance of major ionic species

The water samples when plotted on the variation diagrams for assessing the comparative abundance of major cationic and anionic species present in the groundwater, various X–Y plots have been prepared which indicate that it falls along the 1:1 equiline Fig. 6. From these plots, the following points can be explained. The concentration of HCO_3^- versus Cl^- is plotted in Fig. 6a. The plot shows that HCO_3^- is enriched than Cl^- in most of the samples of the pre- and post-monsoon seasons. The interference that may be drawn is that the chemical species involving HCO_3^-, such as, bicarbonates of Ca^{2+}, Mg^{2+}, Na^+, K^+ are far more abundant than Cl^-. However, bicarbonates show a temporal increase in their concentration in groundwater during the pre- and post-monsoon.

The relative abundance of Cl^- and SO_4^{2-} is described in Fig. 6b. Most of the samples fall below the equal concentration line suggesting that relative dominance of Cl^- over SO_4^{2-} from the pre- to post-monsoon. The alkali elements show a higher concentration when compared with alkaline earth metals (Ca^{2+} and Mg^{2+}) in both seasons, as most of the samples plot above the equal concentration line Fig. 6c. The abundance of HCO_3^- over $Cl^- + SO_4^{2-}$ (Fig. 6d) shows that most points fall above the equal concentration line. Fig 6e shows an abundance of HCO_3^- over ($Ca^{2+} + Mg^{2+}$) suggesting a relative abundance of HCO_3^- in both seasons. Relative abundance of Cl^- and alkalis (Fig. 6f) shows that most of the samples (89%) have $(Na^+ + K^+) > Cl^-$ above 1:1 line in the pre- and post-monsoon. Few samples (11%) fall below the equiline suggesting the relative dominance of Cl^- over $Na^+ + K^+$ in the pre- and post-monsoon seasons. Alkalis versus SO_4^{2-} plot in (Fig. 6g) shows that alkalis are much higher in concentration than SO_4^{2-} and all samples plot below the equal concentration line.

3.1.6 Correlation of physicochemical parameters of groundwater

The correlation coefficient is a statistical parameter which is used to ascertain the relationship between variables. In simple terms, it measures how well variables predict the others [42]. The correlation coefficients for the 36 groundwater samples of the study area are presented in Table 2. Most of the pre-monsoon samples exhibit a good positive correlation between Cl^-, Na^+, K^+ with EC, TDS and Mg^{2+} with TH; Cl^- shows a positive correlation with Ca^{2+}, Na^+, and K^+. Most of the samples have shown a good positive correlation between Cl^-, Na^+, K^+ with EC, TDS, and Ca^{2+} with TH; Cl^- show a positive correlation with Na^+ and K^+ in the post-monsoon season. As noted earlier, water samples having higher contents of salts are characterized by higher values of electrical conductivity (EC). Na^+ and Cl^- ions show a strong positive correlation with TDS and EC Table 2. Thus, the anomalously high values of EC in the studied samples can be ascribed to the higher contents of salts.

4 Conclusions

The hydrogeochemical data of the groundwater samples from the district of Ghaziabad reveals that it is slightly acidic to alkaline in nature and fresh to brackish, hard to very hard type. And pertaining to TDS concentrations; out of 36 samples, 28 samples (78%) from the study area are under the permissible limit and suitable for drinking and irrigation purposes while remaining 8 samples (22%) of the total samples are not suitable for drinking during the pre-monsoon. During the post-monsoon, 67% of the samples are found suitable for drinking as well as irrigation purposes while 33% of the samples are not found suitable for drinking purposes. During the pre-monsoon season, the abundance of major cations and anions of the water samples are Na^+, Mg^{2+} followed by Ca^{2+} and Cl^-, HCO_3^-, Cl^- followed by SO_4^{2-}, respectively. According to the Piper diagram, most of the groundwater samples were characterized by Na^+–HCO_3^- type. In which Na^+/K^+ cations and CO_3^{2-}/HCO_3^- anions are dominant in groundwater. 83% concentration of nitrate ion rises above the permissible limit of WHO (> 45 mg/l) for drinking purpose. The concentration of fluoride is below the permissible limits indicating that it is appropriate for drinking purpose except for the two locations. Gibbs diagram reveals that the majority of the samples are falling in the rock dominance type barring few locations. A major part of the sample barring to reveals that it is appropriate for the irrigation as per [41]. But the samples studied are not suitable for drinking as against the irrigation. Hence, as per the above analysis, it can be concluded that the water of the study area is worryingly polluted owing to the anthropogenic and extensive industrial activities as well as uncontrolled use of agricultural pesticides and other fertilizers. If the situation is not controlled in the future, it may assume an alarming situation for inhabitants. Therefore, great attention should be given to reduce the pollution load.

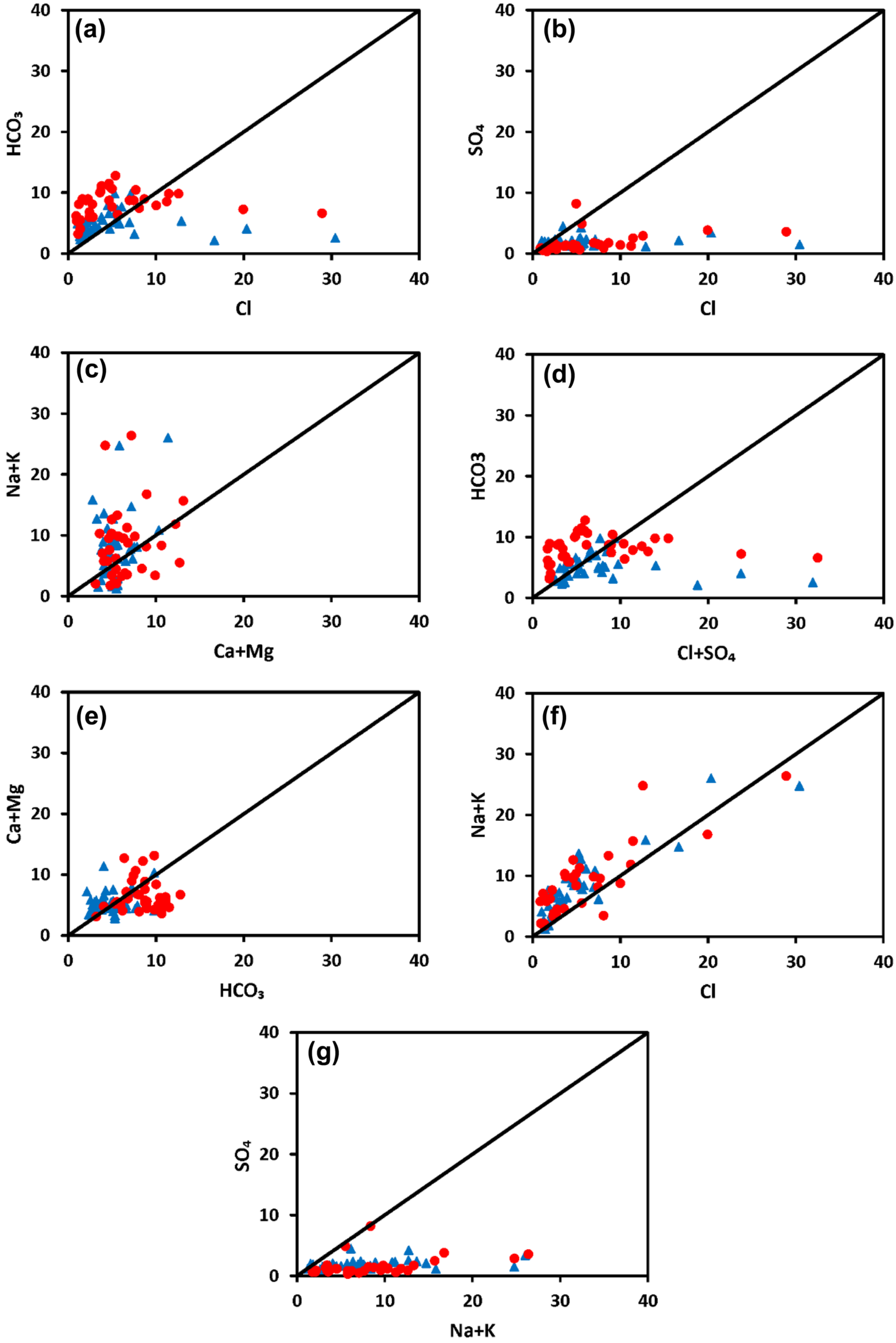

Fig. 6 **a–g** Inter ionic relationship (meq/l)

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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