

# Hydrogeochemical assessment of Moradabad city, an important industrial town of Uttar Pradesh, India

Naseem us Saba<sup>1</sup> · Rashid Umar<sup>1</sup>

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**Abstract** An attempt has been made to understand the hydrochemistry of Moradabad city, a major industrial town of western Uttar Pradesh. For this purpose a total of 188 samples for both the seasons (pre- and post-monsoon of 2012 and 2013) were collected and analyzed for major cations ( $\text{Na}^+$ ,  $\text{K}^+$ ,  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ ) and anions ( $\text{Cl}^-$ ,  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ ,  $\text{NO}_3^-$  and  $\text{F}^-$ ) and 14 samples collected in 2013 were analyzed for trace elements. The groundwater is slightly acidic to alkaline in nature and moderately hard to very hard. Elevated concentration of most of the major ions and trace elements is observed in the area. On the basis of Piper Trilinear plot groundwater has been identified as Na–Cl– $\text{SO}_4$  type in pre-monsoon and Na– $\text{HCO}_3$  type in post-monsoon season. Base-exchange indices along with meteoric genesis indices demonstrate that groundwater in all the four seasons belong to alkali bicarbonate type and are of shallow meteoric water percolation type. The concentration of the trace elements like (Al, Fe, Se and As) is higher than the permissible limits. Correlation of  $\text{SiO}_2$  with Cl and TDS was done to assess the processes responsible for altering the groundwater chemistry. Water quality index maps show that the groundwater in the north eastern and central parts of the study area is unsuitable for drinking purpose. A comparison of spatial distribution of EC and Cl with those of WQI depicts a strong correlation. The study, thus, suggests the poor groundwater quality of Moradabad city. Urban sprawl, population explosion, industrial expansion heavily affected the water quality of the study area.

**Keywords** Groundwater · Trace elements · Water Quality Index · Moradabad city

## Introduction

Groundwater quality assessment is important as increasing urbanization, industrialization, population explosion putting tremendous pressure on groundwater resources and risk of contamination (Ackah et al. 2011; Sayyed and Wagh 2011; Tiwari 2011). The consumption of groundwater for various purposes such as drinking, domestic, agricultural or for industrial use is dependent on the chemical composition of groundwater, thus an understanding of the geochemical composition of groundwater is necessary for the sustainable development of water resources. The chemistry of groundwater system of a particular area is unique which may be altered chemically depending upon several factors such as soil–water interaction, dissolution of mineral species and anthropogenic impacts (Stallard and Edmond 1983; Faure 1998; Subba Rao 2001; Umar and Absar 2003).

The slow percolation of groundwater flowing through rocks results in dissolution of minerals and equilibrium can be reached between groundwater and the minerals. The dissolution of minerals in groundwater describes its chemical behavior. Precipitation and infiltration of water are the two important processes determining the chemistry of a groundwater system. The organic compounds present in the soil zone make water more acidic in nature and this causes the exchange of various elements between water and the surrounding rocks (Deutsch 1997).

The main factors that control groundwater chemistry include rock forming minerals and soils of the area, climate, and vegetation cover. These factors are also

✉ Naseem us Saba  
sabaamu08@gmail.com

<sup>1</sup> Department of Geology, Aligarh Muslim University,  
Aligarh 202002, India

responsible for the spatial and temporal variations in groundwater chemistry (Rajmohan and Elango 2004). Groundwater contamination occurs when the contamination loaded on the ground surface exceed the detoxification capacity of soil, bypass the protective soil horizon and reach the groundwater table (Khan et al. 2015). Pollution once entered into the groundwater system remains concealed for many years, rendering its unsuitability for human consumption (Raju 2012). Groundwater problems and its quality are more severe in densely populated and highly industrialized areas. A substantial alteration in groundwater chemistry occurs due to contaminants arising from various agricultural activities such as excessive use of fertilizers, pesticides, insecticides (Kelly 1997; Stigter et al. 1998; Kraft et al. 1999). The rapid growth of urban centres deteriorates the groundwater quality at a faster pace due to improper disposal of industrial waste without prior treatment and irregular utilization of groundwater resources (Jameel and Sirajudeen 2006). The study conducted by Misra (2011) shows the impact of urbanization on hydrology of Ganga basin indicating a potential effect on environment, water resources and its quality, soil salinity and urban infrastructures.

Trace elements are also the persistent pollutants degrading water quality. Trace elements though very minute in concentration are a threat to the environment and also contaminate groundwater system by continuous leaching thus posing serious health risk to environment and humans as well. Aquifer material, quality of recharge water and the interaction between water and aquifer material are some of the natural factors on which the distribution of trace elements depend upon. Apart from these natural factors human activities also contribute in the distribution of trace elements which are responsible to alter the groundwater system (Helena et al. 2000).

A number of detailed studies on groundwater quality, heavy metals in groundwater, major ion chemistry and the processes controlling groundwater chemistry have been carried out in different parts of India (Umar and Absar 2003; Thilagavathi et al. 2012; Singh et al. 2012a, b; Senthilkumar and Elango 2013; Kumar et al. 2014; Rai and Saha 2015). Similar studies have also been made in the Ganga Plain (Umar et al. 2000, 2006, 2009; Raju et al. 2009; Saha 2009).

A study has been carried out by Lapworth et al. (2014) to investigate the response of groundwater resources to agricultural activity in Punjab state. The study reveals the declining trend in shallow groundwater levels in pre-monsoon season. Higher concentration of  $\text{NO}_3$  and Cl and median concentration of Pb, Cr, Cu, Ni and Zn in shallow groundwater is observed in comparison to deep groundwater. Further the study suggests that shallow aquifer is

vulnerable to contamination from both agricultural and urban sources particularly for  $\text{NO}_3$  and heavy metals.

The hydrochemical analysis of groundwater samples both from shallow and deep aquifers carried out by Krishan et al. (2014) in Bist-Doab catchment, Punjab, reveals the higher concentration of various ions in shallow groundwater compared to deep groundwater and also suggest good quality of water in terms of trace elements (Cr, Mn, Fe). However,  $\text{NO}_3$  and few trace elements (B, Zn, Pb and Cu) at some sites indicate contamination in shallow aquifers. The concentration of uranium is high both in shallow as well as deep aquifers.

In another study, the impact of anthropogenic activities on groundwater quality in Punjab state has been discussed by Purushothaman et al. (2013) and Singh et al. (2012a, b). High concentration of  $\text{NO}_3$ ,  $\text{SO}_4$  and Cl were reported in the study suggesting the deterioration of groundwater quality by land use activities, synthetic fertilizers, and irrigation return flow.

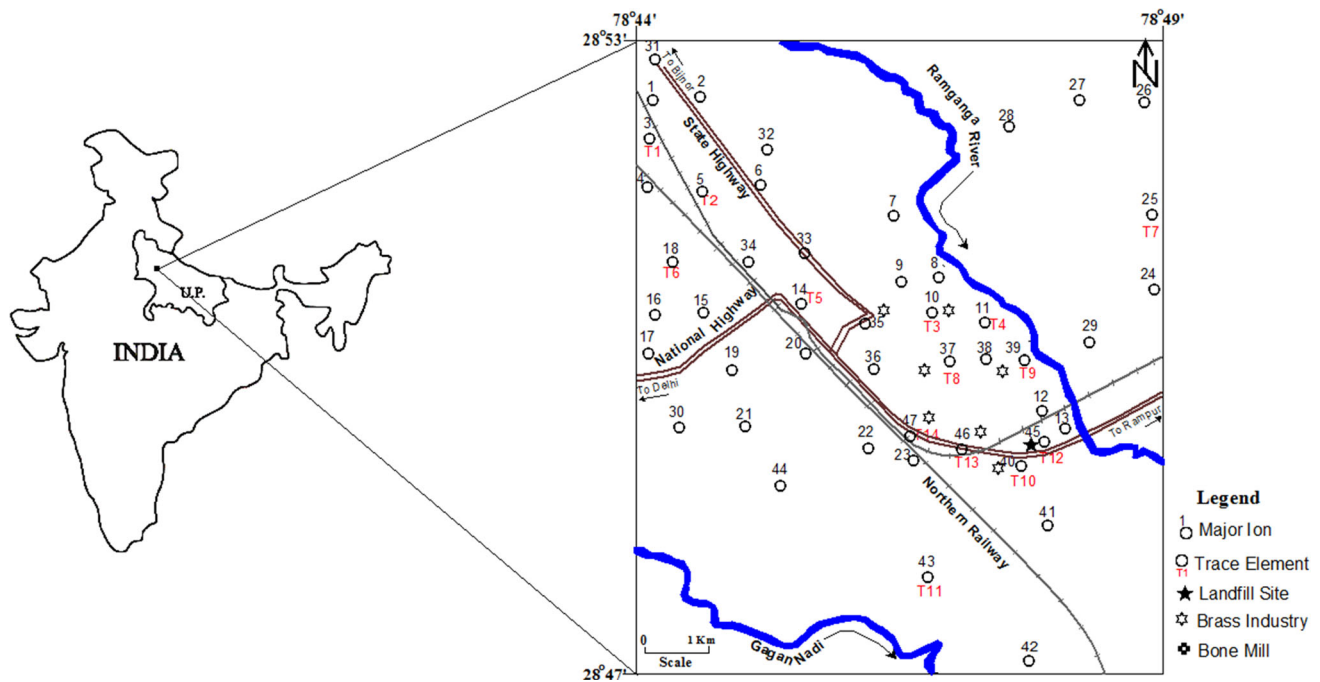
The background given above has created the need to carry out present study in Moradabad city. Moradabad city is one of the most populous city of Uttar Pradesh and also one of the largest producing and exporting centre of brasswares in India. The rapid development in recent decades has an adverse impact on the quality of groundwater. Keeping in view the frequent degradation of water quality, the present study has been done to decipher the chemical variations in groundwater by various natural and anthropogenic factors to assess the suitability of groundwater for drinking purpose. Conventional graphical representations and indices are used to classify the groundwater of the area into various groups. Water Quality Index maps have also been prepared.

## Study area

The study area, Moradabad city lies between two rivers namely river Ramganga at its north eastern margin and Gagan at south eastern margin. It lies between the latitude  $28^\circ 47'$  to  $28^\circ 53' \text{N}$  and  $78^\circ 44'$  to  $78^\circ 49' \text{E}$  covering an area of about  $88 \text{ km}^2$  (Fig. 1).

Moradabad is a major industrial city and is famous for its huge export of brass handicrafts and is also called “Brass City”. Moradabad city in several years has undergone rapid industrial development. There were 82 registered units in the district in year 2000 and this figure has increased to 5487 in 11 years i.e. from 2001 to 2011 (DIC, Moradabad). There are about 600 export units and 5000 industries in Moradabad district.

The area falls in the sub tropical region and the climate is classified as tropical to sub tropical type. The climate is characterized by a hot summer and bracing cold winter



**Fig. 1** Map showing sampling locations

associated with general dryness, except during the south west monsoon when humidity is high. The rainy season extends from end of June to September or part of October. About 86 % of rainfall takes place from June to September. During monsoon surplus water is available for deep percolation to groundwater. The average annual rainfall is 967 mm.

The study area forms a part of Central Ganga Plain and is underlain by alluvial deposits of Quaternary age. This alluvium is a pile of unconsolidated sediments made up of sequence of clay, silt, calcareous nodules, locally known as Kankar and different grades of sand and occurrence of gravel at depth is also occasionally reported. Calcareous nodules, indicative of sedimentation gaps, occur as thin beds and lenses. The Central Groundwater Board has carried out six exploratory drilling to decipher subsurface aquifer geometry, to determine the aquifer parameters and quality of subsurface water. The sediments down to 390 m can be broadly divided into two aquifer groups. The upper aquifer extending to a depth of 180 m is being exploited extensively by state and private tubewells. The second potential aquifer group below 180 m depth, still remains to be fully harnessed for optimum utilization. The cumulative thickness of screened granular zones in these aquifer groups varies from 36 to 112 m. The average yield varies from 1445 to 5220 lpm for drawdown ranging from 1.85 to 8.7 m (CGWB 2008).

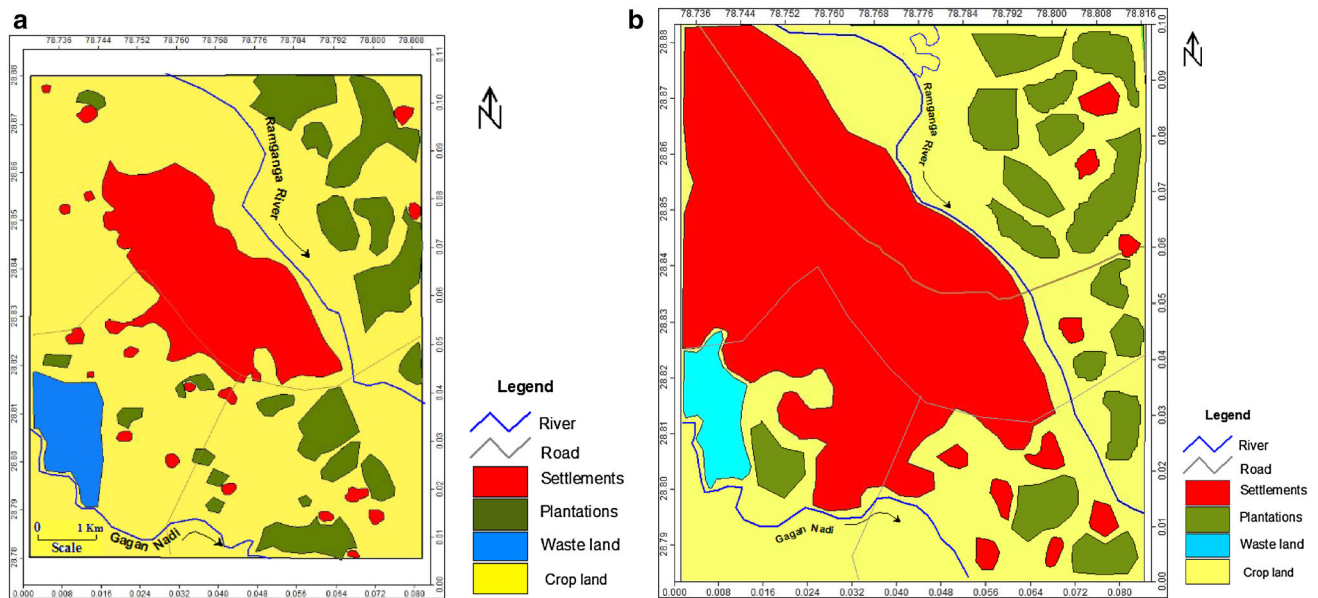
Subsurface lithological data available from shallow boreholes to a maximum depth of 130 m bgl of the area

indicate that top clay layer is persistent throughout the area and is underlain by more porous granular zone intervened by several clay lenses. Depth to water level varies from 3.2 to 13.7 m bgl and from 3.8 to 12.1 m bgl in pre- and post-monsoon season 2012, respectively. The general flow direction of groundwater is from north west to south east with some local diversions.

Landuse/land cover mapping of the area has been done to identify the changes in land cover patterns (Fig. 2a, b). For this purpose, toposheet of 1971 covering the study area and Google Earth imagery of 2013 were used. The area has been categorized into three main land use classes. A comparison of Fig. 2a, b reveal that the area covered by settlements has increased substantially during the period from 1971 to 2013. Area occupied by plantations in north eastern part has also increased. However, the reduction in the area occupied by waste land in the period between 1971 and 2013 has been observed. The increase in the settlements in the study area is due increase in industrialization and urbanization which has potential impact on hydrogeological regime of the area.

## Methodology

A total of 188 groundwater samples, 47 for each season (pre- and post-monsoon seasons) of 2012 and 2013 were collected from hand pumps in well rinsed 1-L polyethylene bottles to evaluate the variation in chemical composition of



**Fig. 2** Land use/Land cover map prepared from **a** Toposheet (1971) and **b** Google Earth imagery (2013)

groundwater. All the samples were collected after 3–5 min pumping of the well to remove the stagnant water in the well assembly. Electrical conductivity (EC), total dissolved solids (TDS) by Hach sensION+ EC5 Portable Conductivity Meter and pH were measured using Hach sensION portable pH meter. The groundwater samples were then analyzed for major ions: cations (Ca, Mg, Na and K) anions (Cl, SO<sub>4</sub>, HCO<sub>3</sub> and NO<sub>3</sub>) following the standard methodologies (APHA 1992). Hardness and calcium were determined by titration method using EDTA; bicarbonate was determined by titration using HCl; chloride was determined using AgNO<sub>3</sub> in titration method; sodium and potassium were measured by flame emission photometry, sulphate was analyzed by gravimetric method; nitrate was determined by colorimetric method using phenol disulphonic acid and fluoride were measured by the spectrophotometer using SPADNS [sodium 2-(parasulfophenylazo)-1,8-dihydroxy-3,6-naphthalene disulfonate]. Silica was analyzed by blue molybdenum silicate method.

Samples collected for trace element analysis were filtered and acidified with HNO<sub>3</sub>. A set of trace elements like Al, Cr, Fe, Co, Ni, Cu, Zn, As, Se, Cd, and Pb were analysed at Geochemistry Laboratory, NGRI, Hyderabad, India using Inductively Coupled Plasma Mass Spectrometer (ICP-MS). Calibration of the instrument was performed using the certified reference material NIST 1640a (National Institute of Standards and Technology, USA), to minimize matrix and other associated interference effects. Another certified reference material for trace elements in water NIST 1643e (National Institute of Standards and Technology, USA) was analyzed as an unknown to check the precision and accuracy of the analysis. Blanks were

analyzed along with the samples and corrections were carried out accordingly. The Relative standard deviation (RSD) was found to be better than 6 % in the majority of the cases, which indicates that the precision of the analysis is reasonably good (Satyanarayanan et al. 2007). Filtered sample was then introduced into the instrument conventional pneumatic nebulization, using a peristaltic pump with a solution uptake rate of about 1 ml/min (Balaram and Rao 2003).

## Result and discussion

### Temporal variation trends of major ions

Results of the water analysis for pre- and post-monsoon samples for the year 2012 and 2013 (Table 1a, b) have been used to identify the processes and mechanisms affecting the groundwater chemistry of the study area.

A summary of chemical trends of major ions over pre- and post-monsoon 2012 and 2013 seasons is presented in Table 2 and the order of dominance of major cations and anions is shown in Table 3. The significant characteristics of major ions are given below:

- Groundwater of the study area is acidic to slightly alkaline in nature (6.1 to 8.2 in pre-monsoon 2012 and 2013) and 6.6 to 8 in post-monsoon 2012 and 2013.
- The average EC values in the area range between 190 to 2950  $\mu\text{S}/\text{cm}$  and 151 to 2025  $\mu\text{S}/\text{cm}$  in pre- and post-monsoon, 2012, respectively. In pre- and post-monsoon

**Table 1** Results of chemical analysis of groundwater samples in mg/l

S. no.	Location	Ca	Mg	Na	K	HCO <sub>3</sub>	Cl	SO <sub>4</sub>	NO <sub>3</sub>	SiO <sub>2</sub>	F	pH	EC (μSeimens)	TDS	Hardness
(a) June 2012															
1	Harthala	40	24	90	0	207	26	192	3.4	68	0.56	7.41	420	269	200
2	Harthala P O	22	25	79	0	205	20	181	1.9	46	0.38	7.82	343	219	160
3	H. Bone Mill	64	61	102	28	193	165	226	1.2	37	0.72	7.18	2680	1714	824
4	Sonakpur	21	38	79	1	208	26	169	6.1	45	0.55	8.12	436	279	208
5	Fakhipura	35	45	200	8	208	256	250	24	62	0.56	7.31	1105	707	312
6	Tubewell Clny	21	27	69	4	247	45	120	9.2	23	0.18	7.34	891	570	164
7	Z. Parishad Clny	16	23	160	4	156	74	246	51	16	0.45	8.25	903	579	340
8	Daulatbagh	19	23	128	38	208	97	188	8.1	37	0.56	7.79	942	603	264
9	Shantinagar	27	32	69	0	169	34	179	3.3	35	0.66	8.17	459	294	200
10	Lal Masjid	72	61	201	26	104	298	451	165	57	0.77	7.32	2950	1890	712
11	Faizganj	35	89	180	8	350	213	337	55	35	0.47	7.33	2370	1516	452
12	Katghar	90	43	80	4	182	60	177	23	62	0.74	7.55	896	575	284
13	HafizSahab	16	32	106	5	257	20	175	3.9	21	0.63	8.06	486	311	172
14	Locoshed Clny	19	20	110	12	234	37	159	3.9	63	0.29	7.61	752	481	132
15	Mirpur	26	42	63	4	208	26	187	2.2	22	0.6	7.85	475	304	236
16	Khushalpur	19	29	90	2	143	17	156	3.1	60	0.35	7.81	437	280	168
17	Mayanagar	19	31	110	2	244	14	197	2	61	0.25	7.63	403	258	176
18	Tigri	34	15	148	0	252	20	177	4.5	43	0.47	7.71	360	230	144
19	Prakashnagar	34	35	100	17	273	54	181	0	64	0.23	7.38	896	574	228
20	Chiria Tola	32	21	122	7	221	43	160	3.2	62	0.29	7.85	757	484	168
21	Dhakka	40	18	122	5	182	23	181	2.8	32	0.4	7.73	501	321	172
22	Jaintipur	29	26	126	9	260	62	167	3	29	0.4	7.59	796	509	180
23	Das Sarai	32	24	90	17	195	82	187	60	29	0.25	7.78	1104	707	260
24	Barwala	24	14	100	20	221	23	195	5.7	25	0.55	7.62	419	268	116
25	Khanpur	24	18	85	4	208	26	187	1.7	39	0.33	7.71	466	298	132
26	Dadupur	27	13	90	7	234	45	153	2.5	59	0.28	7.61	788	504	120
27	Near Dhela	24	19	102	14	234	23	179	2.2	31	0.25	7.68	466	299	140
28	S. Khata	18	36	122	15	208	28	165	2.5	21	0.26	7.59	606	388	192
29	Tajpur	18	23	132	4	283	23	169	1.8	21	0.41	7.54	445	285	140
30	Bhtawali	24	20	120	8	260	20	174	1.6	41	0.25	7.68	458	293	144
31	Mau	24	64	90	7	232	94	199	48	28	0.18	7.49	1056	675	324
32	Muqarrabpur	32	50	126	16	195	128	165	101	21	0.58	7.2	1712	1095	284
33	Officers Colony	22	39	148	4	221	48	196	7.1	56	0.55	7.65	735	471	216
34	Chandranagar	19	19	100	8	195	28	166	1.6	38	0.4	7.97	464	297	124
35	Kanjhri Sarai	26	57	250	5	273	310	192	66	36	0.49	7.54	1096	702	296
36	Malviyanagar	22	19	164	22	169	65	186	5.8	25	0.5	7.46	835	534	132
37	Pakkabagh	43	50	150	13	195	190	189	2.4	54	0.48	7.17	1696	1086	312
38	Mughalpara	24	86	95	8	247	103	197	6	62	0.4	7.56	1231	787	412
39	Jama Masjid	27	39	250	32	351	255	107	7.7	19	0.6	7.28	2010	1285	196
40	Pital basti	21	38	245	30	330	92	392	90	20	0.4	7.3	290	185.6	208
41	Baldevpuri	90	43	160	20	355	130	250	20	19	0.2	7.3	190	121.6	284
42	Milak nagaliya	18	36	280	27	439	150	245	50	28	0.3	7.5	340	217.6	192
43	Pandit Nagla	16	38	230	35	438	75	196	70	22	0.5	7.6	520	332.8	172
44	Mainather	24	18	210	22	410	32	214	40	27	0.9	7.4	832	532.5	132
45	Gulabari	43	50	165	28	340	150	235	60	25	1.63	6.1	2019	1292	312
46	Prabhat market	22	25	298	40	360	146	360	30	26	1.2	6.7	998	638.7	160
47	Sivpuri	19	31	240	30	350	192	251	35	21	0.8	6.6	1211	775	176

**Table 1** continued

S. no.	Location	Ca	Mg	Na	K	HCO <sub>3</sub>	Cl	SO <sub>4</sub>	NO <sub>3</sub>	SiO <sub>2</sub>	F	pH	EC (μSeimens)	TDS	Hardness
(b) November 2012															
1	Harthala	51	21	225	8	429	28	267	1.9	49	0.06	8.02	250	118	216
2	Harthala P O	42	26	200	10	325	37	237	2	50	0.26	7.62	225	117	212
3	H. Bone Mill	107	76	380	39	520	483	328	19.1	50	0.04	7.52	1004	643	580
4	Sonakpur	48	42	190	15	403	34	245	11	60	0.00	7.97	247	158	292
5	Fakhipura	51	23	190	22	230	270	190	47.7	65	0.00	7.55	555	355	224
6	Tubewell Clny	48	49	205	17	481	80	263	24.5	27	0.05	8.48	359	230	320
7	Z. Parishad Clny	43	64	210	16	624	57	216	42.8	30	0.21	7.64	400	256	372
8	Daulatbagh	69	89	230	44	754	128	319	6.2	23	0.00	7.55	495	317	536
9	Shantinagar	34	48	180	11	455	23	235	2.4	26	0.05	7.93	195	125	280
10	Lal Masjid	48	29	290	12	550	57	400	37	28	0.08	8.03	333	213	240
11	Faizganj	69	7	300	50	650	216	180	134	49	0.16	7.34	909	581	200
12	Katghar	56	54	250	12	676	90	264	12.3	25	0.24	7.87	325	207	360
13	HafizSahab	56	58	210	13	494	34	342	2.2	25	0.42	8.5	305	195	376
14	Locoshed Clny	61	58	180	21	585	51	326	2.9	25	0.17	7.88	332	212	392
15	Mirpur	35	45	215	11	494	54	304	2.3	63	0.23	8.33	173	111	272
16	Khushalpur	45	31	210	10	520	26	327	2.4	58	0.25	8.01	177	113	240
17	Mayanagar	32	44	155	9	481	28	246	17.2	10	0.20	8.22	161	103	260
18	Tigri	48	39	160	10	481	8.5	231	0.9	25	0.15	8.02	151	97	280
19	Prakashnagar	56	29	200	19	494	57	264	2.2	28	0.00	8.4	272	182	260
20	Chiria Tola	59	35	275	21	702	60	280	1.3	28	0.00	8.34	340	218	292
21	Dhakka	55	45	175	15	559	45	286	1.9	68	0.00	8.16	210	134	320
22	Jaintipur	55	41	170	22	520	48	238	4	31	0.00	7.89	277	177	304
23	Das Sarai	74	23	320	32	780	108	227	4.5	58	0.09	7.64	474	303	280
24	Barwala	35	68	215	19	468	91	281	31	40	0.00	8	208	132	368
25	Khanpur	45	31	200	15	390	102	256	28.1	41	0.00	7.97	240	156	240
26	Dadupur	72	22	240	20	520	85	284	28.6	25	0.00	7.83	343	219	272
27	Near Dhela	42	48	220	13	572	34	339	22.6	34	0.01	7.64	259	168	300
28	S. Khata	40	32	250	12	533	45	284	21.7	28	0.00	7.76	207	132	232
29	Tajpur	38	36	195	13	390	26	246	28.1	28	0.03	8.14	209	134	244
30	Bhtawali	61	20	215	16	481	37	193	40.2	25	0.00	7.88	305	194	236
31	Mau	67	31	220	19	650	80	174	27.1	65	0.05	7.78	359	230	296
32	Muqarrabpur	74	39	290	31	650	119	211	37	56	0.07	7.48	615	394	344
33	Officers Colony	58	39	220	17	533	60	283	30.3	66	0.00	8.44	314	201	304
34	Chandranagar	77	40	240	19	780	57	257	27.6	58	0.00	7.77	322	205	356
35	Kanjhri Sarai	64	50	340	19	559	320	192	48.4	63	0.10	7.59	428	274	364
36	Malviyanagar	56	45	160	34	455	80	243	2.8	24	0.01	7.77	354	226	324
37	Pakkabagh	88	13	400	33	780	162	249	119	64	0.03	7.43	762	486	272
38	Mughalpara	48	20	210	30	286	128	293	5.2	63	0.04	7.4	769	470	204
39	Jama Masjid	64	34	370	90	670	310	309	5.8	58	0.00	7.28	771	494	300
40	Pital basti	29	35	320	37	380	198	390	85	19	0.1	7.3	299	191	216
41	Baldevpuri	58	39	165	35	360	78	318	25	22	0.05	7.4	330	211	304
42	Milak nagaliya	64	34	220	30	445	170	250	53	32	0.7	7.5	355	227	300
43	Pandit Nagla	64	50	250	39	480	250	290	72	28	0.9	7.8	372	238	364
44	Mainather	30	38	290	27	450	249	260	42	19	0.8	7.2	453	290	232
45	Gulabari	56	45	330	45	370	350	389	55	24	1.61	6.6	2025	1296	324
46	Prabhat market	77	40	260	45	390	280	350	25	27	1.4	7.9	477	305	356
47	Sivpuri	72	22	270	35	398	219	330	40	21	1.2	7.8	1250	800	272



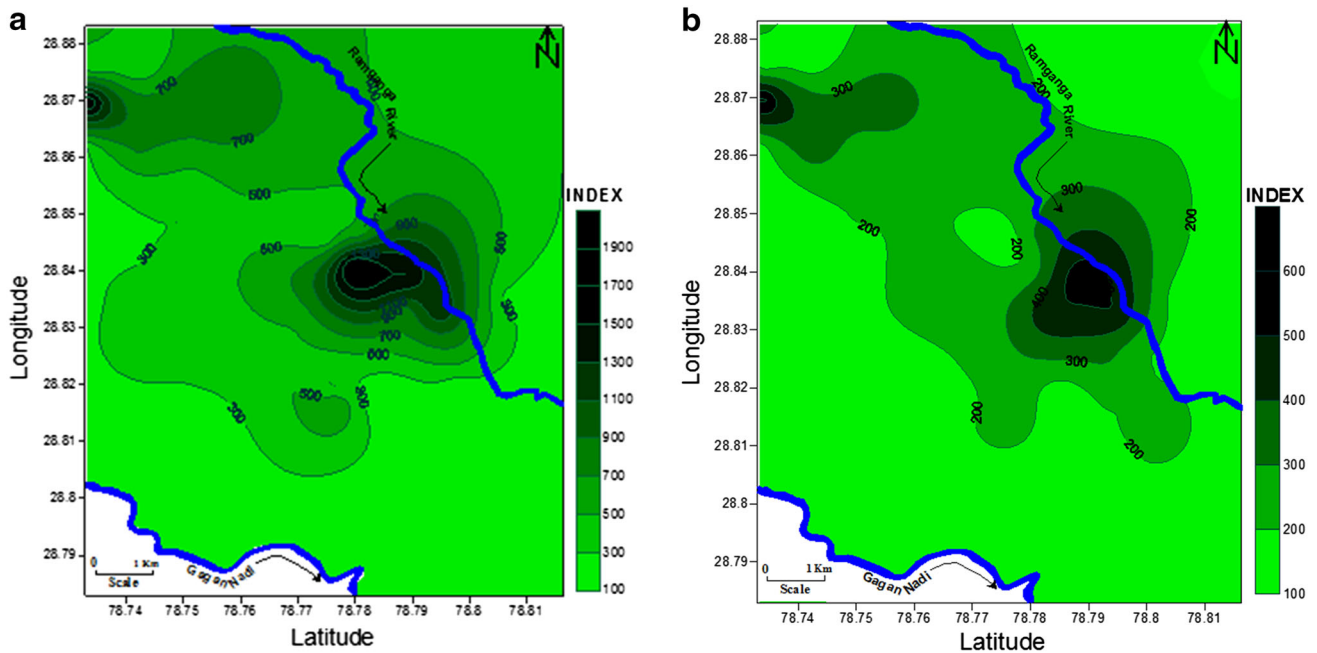
**Table 2** Range of concentration of major cations and anions (in mg/l)

	Pre-monsoon 2012	Pre-monsoon 2013	Post-monsoon 2012	Post-monsoon 2013
<b>Major cations</b>				
Ca	16–90 ( <b>30</b> )	8–69 ( <b>31</b> )	29–107 ( <b>56</b> )	27–160 ( <b>68</b> )
Mg	13–89 ( <b>35</b> )	5–162 ( <b>43</b> )	7–89 ( <b>39</b> )	2–131 ( <b>34</b> )
Na	63–298 ( <b>140</b> )	120–435 ( <b>220</b> )	155–400 ( <b>239</b> )	50–260 ( <b>147</b> )
K	0–40 ( <b>13</b> )	15–96 ( <b>33</b> )	8–90 ( <b>24</b> )	10–60 ( <b>20</b> )
<b>Major anions</b>				
Cl	14–310 ( <b>87</b> )	25–537 ( <b>95</b> )	9–483 ( <b>118</b> )	23–511 ( <b>99</b> )
HCO <sub>3</sub>	104–439 ( <b>248</b> )	304–690 ( <b>438</b> )	230–780 ( <b>515</b> )	221–713 ( <b>344</b> )
SO <sub>4</sub>	107–451 ( <b>204</b> )	64–440 ( <b>257</b> )	174–400 ( <b>274</b> )	34–537 ( <b>233</b> )
NO <sub>3</sub>	0–165 ( <b>23</b> )	0–244 ( <b>33</b> )	1–134 ( <b>27</b> )	0–168 ( <b>26</b> )
F	0.18–1.6 ( <b>0.5</b> )	0.03–1.8 ( <b>0.7</b> )	0–1.6 ( <b>0.2</b> )	0–0.74 ( <b>0.2</b> )

The average values of ions in mg/l are in bold

**Table 3** Order of dominance of cations and anions

Year	Order of dominance of ions
<b>2012</b>	
Pre-monsoon	Na > Mg > Ca > K; HCO <sub>3</sub> > SO <sub>4</sub> > Cl > NO <sub>3</sub> > F
Post-monsoon	Na > Ca > Mg > K; HCO <sub>3</sub> > Cl > SO <sub>4</sub> > NO <sub>3</sub> > F
<b>2013</b>	
Pre-monsoon	Na > Mg > K > Ca; HCO <sub>3</sub> > SO <sub>4</sub> > Cl > NO <sub>3</sub> > F
Post-monsoon	Na > Ca > Mg > K; HCO <sub>3</sub> > SO <sub>4</sub> > Cl > NO <sub>3</sub> > F

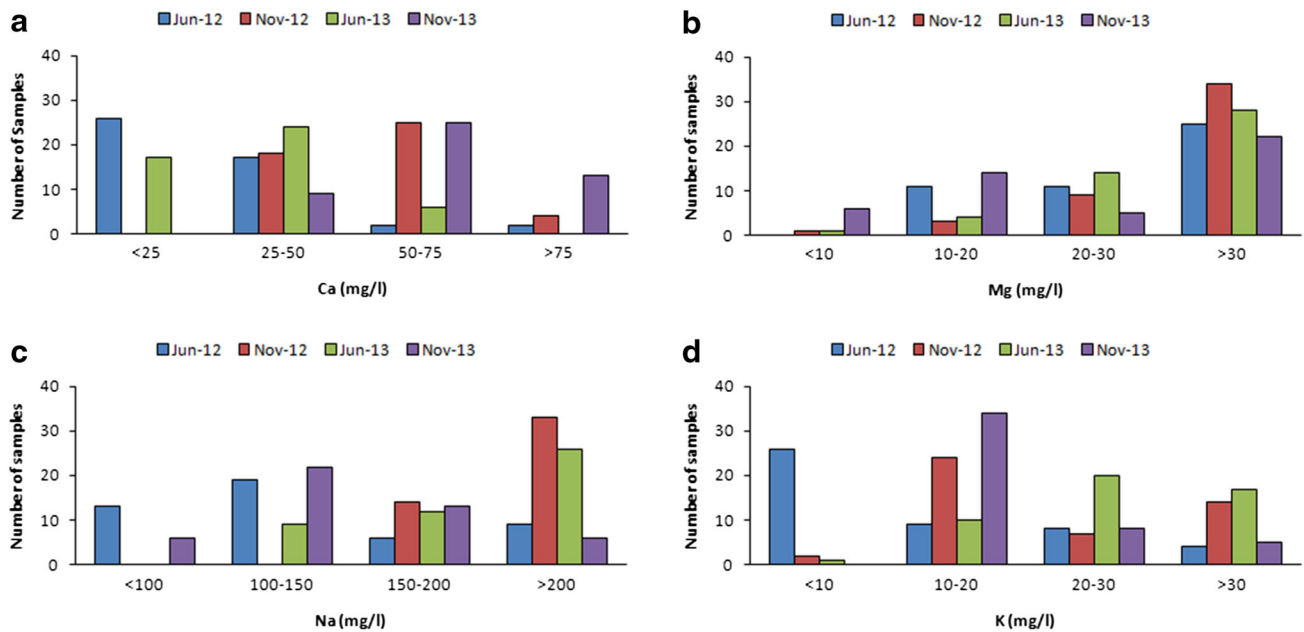


**Fig. 3** Spatial distribution of TDS in mg/l (a June 2012, b November 2012)

2013, EC values range between 106 to 952  $\mu\text{S}/\text{cm}$  and 152 to 947  $\mu\text{S}/\text{cm}$ , respectively.

- TDS is an important parameter in water quality assessment which in the study area range from 122 to 1890 mg/l and 97 to 1296 mg/l in pre- and post-

monsoon season of 2012. The spatial distribution maps of TDS are given in Fig. 3a, b, depicting two high TDS zones. One high TDS zone is in the central part of the area where TDS is >1000 mg/l, the other high TDS zone is in north western part with TDS ranging from



**Fig. 4** Temporal variations of cations

800 to 1200 mg/l. During post-monsoon season (November), only one sample has TDS >1000 mg/l.

- Hardness in the area ranges from 116 to 824 mg/l in pre-monsoon and 200 to 580 mg/l in post-monsoon 2012. In 2013 hardness varies from 132 to 780 and 148 to 800 mg/l in pre- and post-monsoon season, respectively. Thus, groundwater of the area is hard to very hard in nature.
- Calcium ranges from 8 to 90 mg/l in pre-monsoon samples of 2012 and 2013 whereas in post-monsoon season it is 27 to 160 mg/l for the same years (Fig. 4a). Except few samples of pre- and post-monsoon, 2012 and 2013, all the samples have Ca concentration <75 mg/l.
- During the two consecutive pre- and post-monsoon seasons of 2012 and 2013, Mg concentration ranges from 5 to 162 mg/l and 2 to 131 mg/l, respectively. Figure 4b suggests that most of the samples have concentration beyond the limit of 30 mg/l (WHO 1984). So the area is categorized as Mg-enriched as compared to calcium.
- In pre- and post-monsoon season, 2012, Na concentration ranges from 63 to 298 mg/l and 155 to 400 mg/l, respectively. In 2013 pre-monsoon, Na range from 120 to 435 mg/l and in post-monsoon it is 50 to 260 mg/l. Large variation in the concentration of Na is observed. The average values of Na tend to be highest in post-monsoon season, 2012 (Fig. 4c).
- Potassium concentration range from 0 to 96 mg/l in pre-monsoon season of 2012 and 2013 and for the post-monsoon season of the same years it ranges from 8 to

90 mg/l. Almost similar concentration is found in both the years (Fig. 4d).

- Average chloride concentration in pre-monsoon 2012 and 2013 range from 87 to 95 mg/l and for the post-monsoon season it is 99 to 118 mg/l (Fig. 5e). The highest concentration of 537 and 511 mg/l is recorded in sample no. 3 in pre- and post-monsoon season of 2013, respectively. This sample is collected from abandoned bone mill site.
- Average value for  $\text{HCO}_3$  for pre-monsoon 2012 is 248 mg/l. For the other three sets of samples the average values are 515, 438 and 344 mg/l (Fig. 5f). High bicarbonate concentration is observed in the post-monsoon season of 2012 and 2013.
- Sulphate in the area range from 107 to 451 mg/l in pre-monsoon and 174 to 400 mg/l in post-monsoon, 2012. In 2013, the concentration of  $\text{SO}_4$  is 64 to 440 mg/l and 34 to 537 mg/l in pre- and post-monsoon season. The concentration of sulphate has increased in 2013 (Fig. 5g).
- Nitrate is high at some locations in the study area in all the four seasons of 2012 and 2013 reaching to the highest value of 244 mg/l in pre-monsoon 2013 (Fig. 5h). The average value range from 23 to 33 mg/l.
- Concentration of fluoride is within the range (<1.5 mg/l) except 3 samples in both the seasons of 2012 and 2013.

Chemical characteristics of groundwater that emerge from above discussion are as follows:

- High concentration of sodium and potassium.



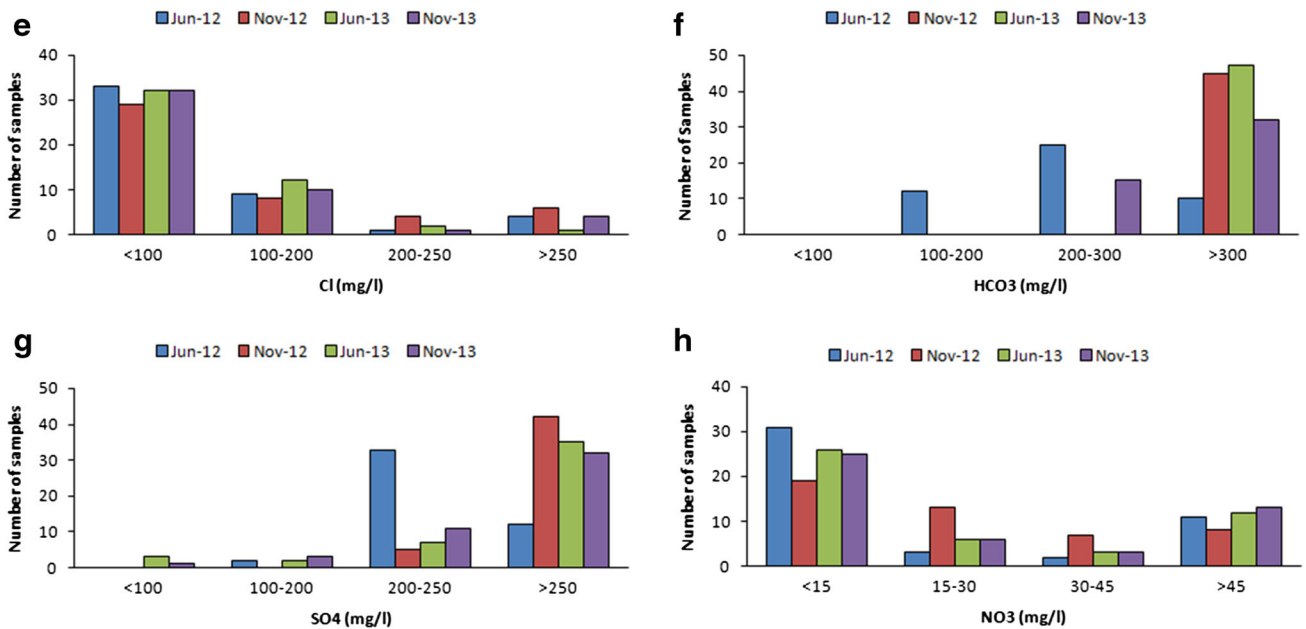


Fig. 5 Temporal variations of anions

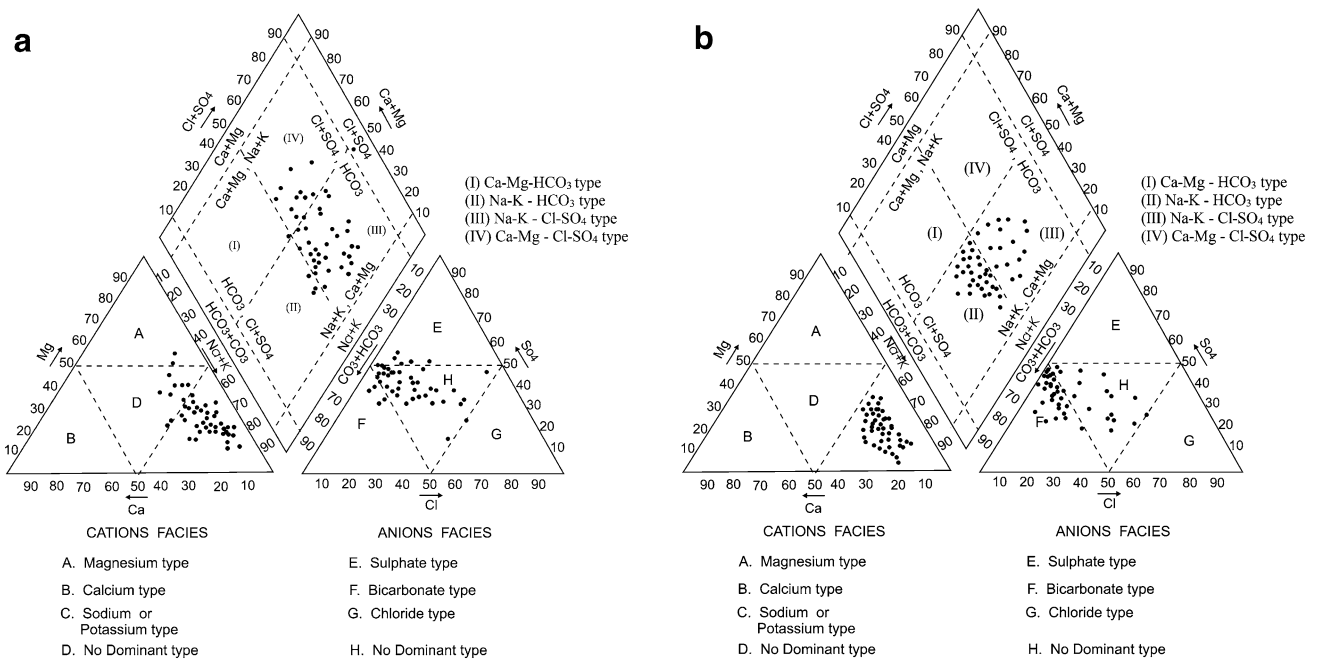


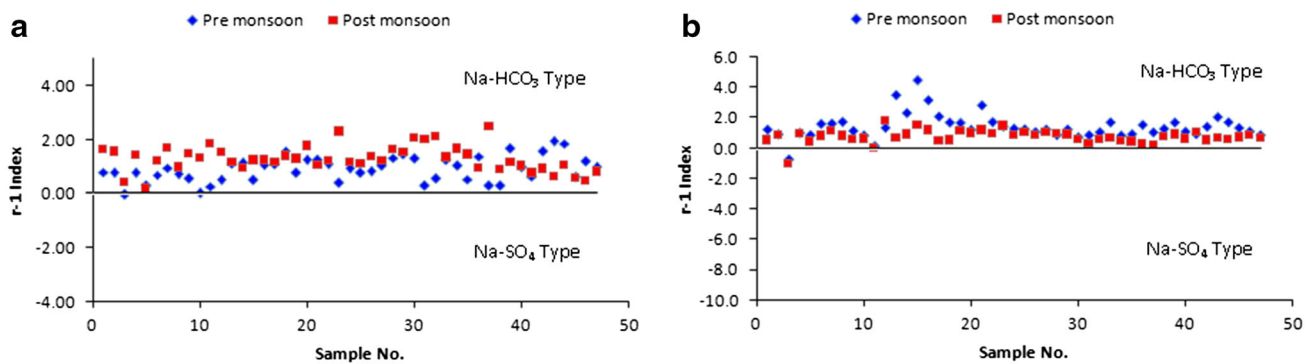
Fig. 6 Piper Trilinear Diagram (a June 2012, b November 2012)

- Relatively Mg-enriched.
- Ca deficient.
- Relatively high concentration of chloride during pre- and post-monsoon seasons of 2013.
- High bicarbonate during post-monsoon of 2012 and 2013.
- Increased sulphate concentration during 2013.
- High nitrate in some samples in pre- and post-monsoon 2012 and 2013.

**Hydrochemical facies**

*Piper's Trilinear diagram*

The Trilinear plot for the pre- and post-monsoon season (Fig. 6a, b) is explained using the facies classification of Back and Hanshaw (1965). Based on this plot, groundwater samples have been classified into four hydrochemical facies



**Fig. 7** a, b Base exchange indices of water samples (2012 and 2013)

- Figure 6a shows that during pre-monsoon alkalis are abundant constituting 77 % of cations and 19 % samples exhibit no dominant character and rest 4 % are magnesium type.
- 81 % samples exhibiting no dominant character, 11 % samples fall in sulphate field while only 8 % samples are rich in bicarbonate type among anions.

In the post-monsoon period of 2012 (Fig. 6b), the relative abundance of cationic and anionic species is as follows:

- Alkalis dominate over alkaline earths in all the samples during post-monsoon.
- In anionic species during post-monsoon, bicarbonate dominate over chloride and sulphate in 64 % of the samples and 36 % samples do not show any dominant anionic signatures.

It is clear from the figures that the dominant facies during pre-monsoon season is Na+K-Cl+SO<sub>4</sub> type followed by Ca+Mg-Cl+SO<sub>4</sub> type and during post-monsoon season change in facies has been observed where 64 % samples are of Na+K-HCO<sub>3</sub> type while the remaining are Na+K-Cl+SO<sub>4</sub> type. The seasonal shifts in the facies during post-monsoon period may be due to the dissolution of gases in the atmosphere and in the unsaturated zone during precipitation and infiltration which imparts high concentration of bicarbonates during post-monsoon season (Shanyengana et al. 2004).

#### Base-exchange indices ( $r_1$ )

Base-exchange indices proposed by Matthes (1982) were used to classify the groundwater samples using the equation:

$$\text{Base-exchange indices } (r_1) = (\text{Na}^+ - \text{Cl}^-) / \text{SO}_4^{2-}$$

where,  $r_1$  is the base-exchange index and Na, Cl and SO<sub>4</sub> concentration in meq/l. If  $r_1 < 1$ , groundwater sources are of Na<sup>+</sup>-SO<sub>4</sub><sup>2-</sup> type and when  $r_1 > 1$ , it indicates

groundwater sources are of Na<sup>+</sup>-HCO<sub>3</sub><sup>-</sup> type. So, on this basis plots have been prepared which indicate that groundwater in both the seasons of both years, i.e. pre- and post-monsoon season of 2012 and 2013 belong to Na<sup>+</sup>-HCO<sub>3</sub><sup>-</sup> type (Fig. 7a, b).

#### Meteoric genesis indices ( $r_2$ )

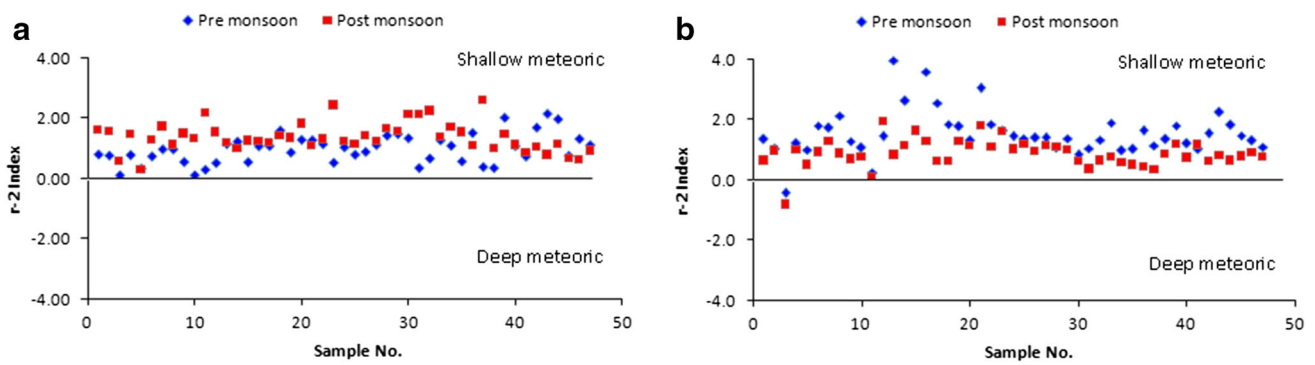
This index is also used to classify the groundwater sources using the following equation:

$$\text{Meteoric genesis indices } (r_2) = (\text{K}^+ + \text{Na}^+) - \text{Cl}^- / \text{SO}_4^{2-}$$

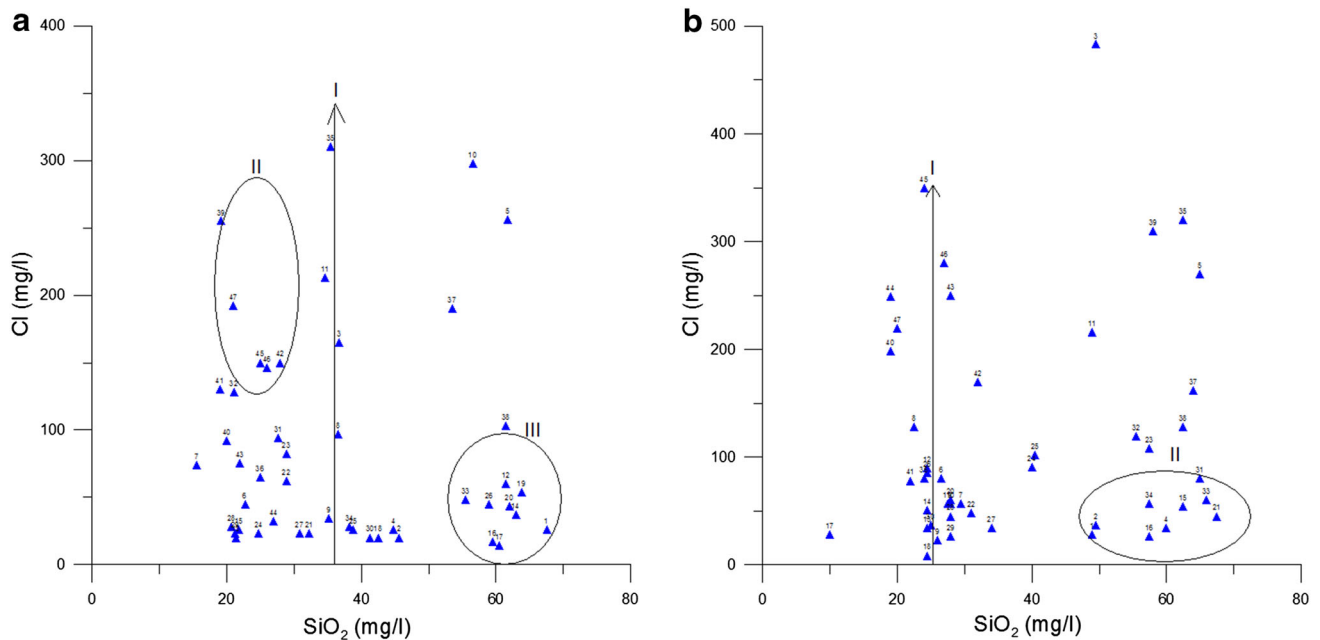
where,  $r_2$  is the meteoric genesis index and K<sup>+</sup>, Na<sup>+</sup>, Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> concentration in meq/l. If  $r_2 < 1$ , the groundwater source is of deep meteoric percolation type whereas  $r_2 > 1$  indicates groundwater source of shallow meteoric percolation type. Based on the meteoric genesis index, it has been observed that all the samples of 2012 and 2013 of both the seasons except one in pre- and one in post-monsoon of 2013, belong to the groundwater source of shallow meteoric water percolation type. From the indices calculated above ( $r_1$  and  $r_2$ ), it has been concluded that the groundwater samples belong to Na<sup>+</sup>-HCO<sub>3</sub><sup>-</sup> type and are shallow meteoric water percolation type (Fig. 8a, b).

#### Silica in groundwater

Silica released as a result of chemical breakdown of silicate minerals in rocks and sediments by chemical weathering is acquired by circulating groundwater and therefore the source of silica (SiO<sub>2</sub>) in groundwater is almost exclusively and unequivocally a result of water-rock interaction (Hem 1989). Concentration of SiO<sub>2</sub> in groundwater varies from 1 to 30 mg/l, the median value being 17 mg/l (Davis 1964). Relatively high silica content in groundwater, therefore, implies more intense water-rock interaction, which, in turn, may be related to various aquifer-related parameters,



**Fig. 8** a, b Meteoric genesis index of water samples (2012 and 2013)



**Fig. 9**  $\text{SiO}_2$  versus Cl plot (a June 2012, b November 2012)

such as permeability, residence time and lithology. Silica concentration in groundwater samples of study area range from 15 to 67 mg/l in pre-monsoon season, averaging 37.5 mg/l. During post-monsoon season, silica concentration ranges from 10 to 67 mg/l, averaging 38.7 mg/l.

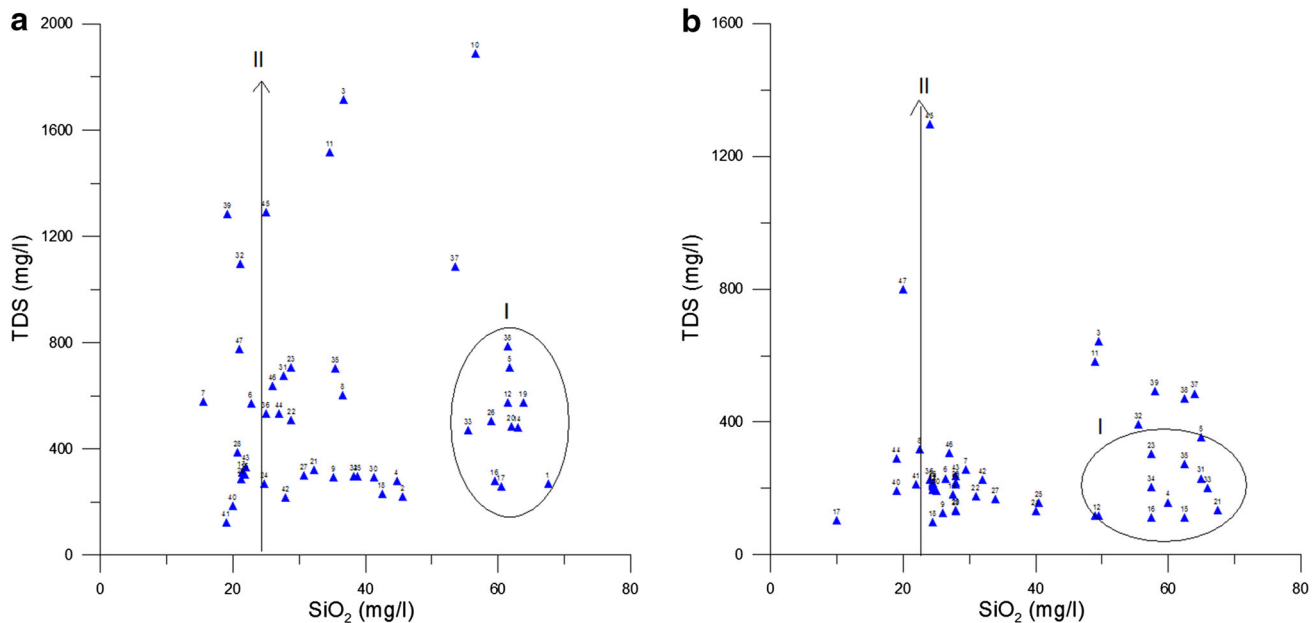
### Relationship of $\text{SiO}_2$ with Cl

Cl acts as an inert element in all natural water–rock environments, i.e. once in solution, it stays there both at ambient and elevated temperatures (Ellis 1970). It is not adsorbed to any marked degree on mineral surfaces (Hem 1970) and usually does not enter common rock-forming minerals due to the large size of its ion. Keeping this in consideration, Cl values have been related to silica concentrations for both the time periods (Fig. 9a, b) to evaluate

the role of anthropogenic and natural activities in ion acquisition.

In  $\text{SiO}_2$  versus Cl plot for pre-monsoon season (Fig. 9a), 3 groups were identified. Group I comprising 5 samples (3, 8, 9, 11, and 35) and group II consists of 5 samples (39, 42, 45, 46 and 47). These groups are defined by  $\text{SiO}_2$  values (38 mg/l for group I and <30 mg/l for group II) and high Cl values (up to 300 mg/l). This suggests that anthropogenic activities are responsible for such high values. Samples 1, 12, 14, 16, 17, 19, 20, 26 and 33 form a cluster defined by high  $\text{SiO}_2$  values of 55 to 67 mg/l and low Cl concentration (<100 mg/l). These may be termed as groundwater that has attained their Cl values through interaction with solid phase.

In  $\text{SiO}_2$ –Cl plot for post-monsoon season (Fig. 9b), 2 groups were identified. Samples 6, 9, 12, 13, 14, 18, 26, 30,



**Fig. 10**  $\text{SiO}_2$  versus TDS plot (a June 2012, b November 2012)

36 and 46 form group I and is defined by  $\text{SiO}_2$  concentration (24–36 mg/l) and high Cl concentration (>300 mg/l). This group suggests that anthropogenic activities have played major role for such chloride values. While group II has low Cl concentration (<100 mg/l) and  $\text{SiO}_2$  values up to 50–67 mg/l. This suggests that rock water interaction is responsible for such  $\text{SiO}_2$  concentration.

### Relationship of $\text{SiO}_2$ with TDS

$\text{SiO}_2$ -TDS plot (Fig. 10a) of pre-monsoon season is described by 2 clusters. Cluster I comprising 11 samples. In this cluster  $\text{SiO}_2$  values range from 55 to 67 mg/l and TDS value range from 269 to 787 mg/l. This suggests that part of TDS in these samples is acquired through water rock interaction. In group II, for  $\text{SiO}_2$  values of 25 mg/l, TDS varies from 268 to >1200 mg/l. This group indicates that water rock interaction has minimum role in acquisition of TDS. Bulk of TDS in this group has been acquired by anthropogenic activities.

11 samples form a cluster in  $\text{SiO}_2$ -TDS plot in post-monsoon season (Fig. 10b). In this group,  $\text{SiO}_2$  ranges from 50 to 65 mg/l and TDS varies from 118 to 355 mg/l. This suggests that TDS in these samples has been acquired through rock water interaction as was observed in pre-monsoon season. The second group also follow the same pattern as was in pre-monsoon season where for  $\text{SiO}_2$  values of 25 mg/l, TDS ranges from 97 to 1296 mg/l. This suggests the role of anthropogenic activities in acquiring such TDS values.

### Trace element distribution in groundwater

Trace elements mobility and occurrence in groundwater are strongly influenced by adsorption on clay minerals, organic matter and other crystalline and amorphous substances that make up the porous media, thus their concentrations in groundwater is controlled by geochemical processes (Deutsch 1997). Occurrence of trace elements also depends upon groundwater pH and redox conditions for example acidic conditions (less than 7) is a significant factor in the occurrence of cationic metals (Al, Fe, Mn, and Ni) while with increase in pH elements such as Cu, Pb, and Zn, adsorb more strongly to aquifer materials (Ayotte et al. 2011).

The elemental anomaly in the groundwater regime once created through natural processes or by unintended or unethical human intervention, often goes unabated. The toxicity of an element depends on the dose, the chemical form, route of exposure, bio-availability, distribution in the body, and storage and excretion parameters. It is clear that metal enters the aquatic system from diverse sources, both point and non-point and can be readily transported from abiotic to biotic system (Khan 2011).

A total of 28 samples for both the (pre- and post-monsoon 2013) seasons were analyzed for eleven trace elements known for their toxic effects. These elements include Al, Cr, Fe, Co, Ni, Cu, Zn, As, Se, Cd and Pb. Concentration of these trace elements for both the seasons in groundwater of study area is shown in Table 4a, b.

**Table 4 a** Trace element data in mg/l in selected groundwater samples

S. no.	Location	Al	Cr	Fe	Co	Ni	Cu	Zn	As	Se	Cd	Pb
(a) June 2013												
T1	Shaktinagar	3.558	0.058	3.941	0.001	0.051	0.042	4.662	0.026	0.087	0.003	0.128
T2	Fakhirpura	0.871	0.050	3.594	0.002	0.066	0.044	1.071	0.033	0.131	0.070	1.707
T3	Lal Masjid	2.367	0.058	3.885	0.002	0.049	0.069	1.475	0.032	0.152	0.009	0.321
T4	Faizganj	6.673	0.055	3.802	0.002	0.083	0.057	1.462	0.032	0.127	0.006	0.185
T5	Locoshed Colony	1.596	0.051	3.493	0.002	0.055	0.033	1.846	0.036	0.108	0.021	0.212
T6	Tigri	8.277	0.072	6.999	0.003	0.126	0.711	0.531	0.032	0.112	0.007	0.217
T7	Khanpur	0.655	0.051	3.900	0.001	0.032	0.040	1.550	0.056	0.112	0.014	0.307
T8	Pakka bagh	3.213	0.052	5.212	0.002	0.057	0.926	1.808	0.033	0.157	0.006	0.274
T9	Jama masjid	0.775	0.050	3.837	0.002	0.038	0.032	1.038	0.089	0.113	0.003	0.083
T10	Pital basti	0.615	0.049	3.550	0.001	0.038	0.023	0.722	0.037	0.116	0.002	0.060
T11	Pndit nagla	0.568	0.048	3.522	0.001	0.029	0.034	0.965	0.053	0.120	0.002	0.065
T12	Gulabari	0.449	0.049	3.616	0.001	0.025	0.023	0.752	0.069	0.138	0.007	0.113
T13	Prabhat market	0.861	0.049	3.587	0.001	0.050	0.026	0.918	0.036	0.128	0.002	0.073
T14	Sivpuri	0.687	0.054	3.657	0.001	0.028	0.031	0.858	0.032	0.124	0.002	0.083
(b) November 2013												
T1	Shaktinagar	0.488	0.038	3.350	0.001	0.037	0.038	4.047	0.026	0.068	0.004	0.124
T2	Fakhirpura	7.142	0.039	4.731	0.002	0.027	0.031	0.456	0.032	0.092	0.002	0.058
T3	Lal Masjid	1.945	0.042	3.829	0.001	0.067	0.078	0.810	0.028	0.080	0.003	0.116
T4	Faizganj	1.375	0.053	3.493	0.002	0.049	0.053	0.897	0.033	0.100	0.006	0.154
T5	Locoshed	22.528	0.071	6.002	0.002	0.024	0.139	1.140	0.033	0.093	0.002	0.056
T6	Tigri	1.876	0.044	3.706	0.001	0.042	0.034	0.664	0.053	0.084	0.002	0.113
T7	Khanpur	7.546	0.040	5.105	0.002	0.024	0.037	0.519	0.034	0.082	0.002	0.052
T8	Pakka bagh	1.864	0.040	3.740	0.003	0.096	0.118	4.824	0.030	0.103	0.006	0.247
T9	Jama masjid	0.304	0.038	3.253	0.002	0.027	0.051	5.228	0.098	0.092	0.002	0.059
T10	Pital basti	0.604	0.042	3.204	0.001	0.024	0.046	0.415	0.034	0.094	0.001	0.051
T11	Pndit nagla	0.762	0.039	3.308	0.001	0.040	0.043	0.705	0.062	0.095	0.008	0.223
T12	Gulabari	0.294	0.040	3.125	0.001	0.020	0.030	0.830	0.058	0.082	0.003	0.090
T13	Prabhat market	0.853	0.040	3.161	0.002	0.026	0.031	0.617	0.024	0.071	0.002	0.138
T14	Sivpuri	0.557	0.036	3.059	0.001	0.021	0.024	0.440	0.028	0.080	0.002	0.109

Aluminium is released to the environment by natural processes and from various anthropogenic sources such as mining and industrial uses. Long lasting intake of significant concentrations of aluminium can lead to serious health effects, such as: damage to central nervous system, dementia, loss of memory, listlessness, degenerative brain disease such as Alzheimer. However, there is controversy on the possible association of Alzheimer's disease and aluminium (<http://www.lenntech.com/periodic/elements/al.htm>).

The maximum permissible limit of Aluminium (Al) is 0.2 mg/l (BIS 1991). Aluminium concentration in groundwater samples is in the range from 0.44 to 8.27 mg/l in pre-monsoon season while it is 0.29 to 22.5 mg/l in post-monsoon season. All the samples have higher values than permissible limits.

Chromium is found in two oxidation states: Cr(VI) and Cr(III), since hexavalent state of chromium is relatively

mobile and is acutely toxic and carcinogenic as well. The maximum permissible limit of Chromium ( $\text{Cr}^{6+}$ ) in drinking water is usually less than 0.05 mg/l (BIS 1991). The concentration of chromium in the study area range from 0.048 to 0.072 mg/l during pre-monsoon while it is 0.036 to 0.071 mg/l during post-monsoon season. Eight samples in pre-monsoon and two in post-monsoon period exceeded the permissible limit. Chromium is an important industrial metal, used for electroplating, paints, dyes, paper industries etc. and has been released to the environment via leakage, poor storage, or improper disposal practices (Palmer and Wittbrodt 1991; Calder 1988).

Iron is a metallic element essential for the formation of haemoglobin in the red blood cells. Excess of iron in drinking water may lead to a disease called hemochromatosis while its deficiency causes anaemia. The recommended limit for iron as suggested by BIS (1991) and WHO (1993) is 0.3 mg/l. All samples in the study area in

both the seasons exceed this limit. High concentration of iron may be due to interaction of iron bearing minerals, leaching of organic matter from the upper soil surface, rusting of pipes or some localized effects.

Nickel (Ni) concentrations in the study area range from 0.025 to 0.126 mg/l and 0.020 to 0.096 mg/l in pre-monsoon and post-monsoon season, respectively. Cobalt (Co) concentrations in the study area range from 0.001 to 0.003 mg/l in both the seasons. Thus, cobalt and nickel concentrations in the study area are within the permissible limits.

Copper is necessary for health, its low concentration is not good for health and in higher concentration it leads to copper poisoning. The concentration of copper in groundwater samples range from 0.023 to 0.926 mg/l and 0.024 to 0.139 mg/l in pre- and post-monsoon season, respectively. Permissible limit for copper suggested by WHO is 0.05 mg/l. Four samples in pre-monsoon and four samples in post-monsoon season exceed this limit. Copper can come in groundwater by both natural phenomenon or by human activities. Probable source of copper in the study area is brassware industries.

Zinc is an essential trace element necessary for all life forms. Zinc concentrations in the study area range from 0.0531 to 4.662 mg/l in pre-monsoon season and 0.415 to 5.228 mg/l in post-monsoon season. Highest desirable limit of zinc as recommended by WHO (1994) is 5 mg/l. According to this limit, all the samples in pre-monsoon season are well within the limits while only one sample in post-monsoon season is above this limit. The source of this ion is may be a result of brass industries running in the area.

Arsenic contamination in groundwater may be due to dumping of untreated discharge and hazardous waste materials from industries (Andreae et al. 1983). The permissible level of arsenic is 0.05 mg/l (BIS 1991). Arsenic concentration in the study area range from 0.026 to 0.089 mg/l in pre-monsoon and 0.024 to 0.098 mg/l in post-monsoon period. It is observed that four samples in pre-monsoon and four samples in post-monsoon are exceed this limit. As arsenic is added in small quantities to alpha-brass to make it dezincification resistant (Davis 2001), this might be the reason for the concentration of this element in groundwater of study area. Arsenic in drinking water can affect the human health and considered as one of the most significant environmental causes of cancer in the world (Smith et al. 1992).

Selenium is essential element at low levels, but at levels higher than permissible limits it can affect the health. In study area, selenium concentration range from 0.087 to 0.157 mg/l and 0.068 to 0.103 mg/l in pre- and post-monsoon season, respectively. All samples in pre-monsoon

and post-monsoon season have higher concentration than the desirable limit of 0.01 mg/l as suggested by BIS (1991). Selenium is released through both natural processes and human activities. It is added to copper, lead, and steel alloys to improve their machinability and to replace lead in brasses for plumbing applications. Other sources of selenium includes municipal waste water, hazardous waste site, copper and lead refinery effluent.

Cadmium is a hazardous element and is considered as carcinogen; it can lead to kidney failure and also can harm the nervous system and immune system (Lenntech 2011). Maximum permissible limit for cadmium in groundwater is 0.01 mg/l. In study area, cadmium range from 0.002 to 0.070 mg/l and 0.001 to 0.008 mg/l in pre- and post-monsoon season. Three samples in pre-monsoon season are exceeding the permissible limit and none of the sample in post-monsoon season cross this limit. Cadmium in drinking water may occur as a result of the presence of it as an impurity in the zinc of galvanized pipes or cadmium-containing solders in fittings, water heaters, water coolers and taps. Cadmium may also come from domestic and industrial activities. Cadmium is used as coating to all ferrous materials, iron, brass and aluminium. These activities may be responsible for the elevated concentration of cadmium in groundwater.

Lead has no known beneficial effects on human health. By its nature it is considered as toxic element as it act as cumulative metabolic poison (Adepoju-Bello and Alabi 2005). The high concentration of lead in water could be attributed to industrial discharge and agricultural activities. Water may have lead from lead components like lead pipes, lead-based copper piping solders and brass fixtures. Lead solders and brass faucet fixtures have been identified as a significant source of lead contamination. Possible sources of lead contamination include diesel fuel consumed extensively in farm lands, discarded batteries, paint and leaded gasoline (Alam and Umar 2013). Lead concentration in pre-monsoon season range from 0.060 to 1.707 mg/l and in post-monsoon season it range from 0.051 to 0.247 mg/l. Nine samples in pre-monsoon season and eight samples in post-monsoon season have lead concentration higher than the permissible limit of 0.1 mg/l as suggested by BIS (1991).

### Water Quality Index

WQI is defined as a rating that reflects the composite influence of different water quality parameters (Sahu and Sikdar 2008). It is an important tool for demarcating groundwater quality for drinking purposes (Tiwari and Mishra 1985; Singh 1992; Subba Rao 1997; Mishra and Patel 2001; Naik and Purohit 2001). It gives a clear picture about the usability of the water for different purposes.



A water quality index denotes the integrated effect of the various parameters that are relevant and significant to a particular use.

For calculating water quality index 28 groundwater samples were taken for pre- and post-monsoon season. The standards for drinking purposes as recommended by WHO (1993) and BIS (1991) have been considered for the calculation of WQI. For computing WQI three steps are followed. In the first step, each of the 14 parameters (TDS, pH, TH, Cl, SO<sub>4</sub>, NO<sub>3</sub>, F, Ca, Mg, Fe, Cu, Pb, Cr, Cd) have been assigned a weight ( $w_i$ ) according to its relative importance in the overall quality of water for drinking purposes.

The maximum weight of 5 has been assigned to the parameters like nitrate, lead, chromium and cadmium due to their major importance in water quality assessment. Total dissolved solids, pH, sulphate, fluoride and iron were assigned weight of 4 due to their comparatively less importance in water quality assessment. Other parameters like total hardness, calcium, magnesium, and copper were assigned weight of 2 depending on their less significant role in water quality determination (Vasanthavigar et al. 2010).

In the second step, the relative weight ( $W_i$ ) is computed from the following equation:

$$W_i = \frac{w_i}{\sum_{i=1}^n w_i}$$

where  $W_i$  is the relative weight,  $w_i$  the weight of each parameter,  $n$  is the number of parameters.

Calculated relative weight ( $W_i$ ) values of each parameter are given in Table 5. In the third step, a quality rating scale ( $q_i$ ) for each parameter is assigned by dividing its concentration in each water sample by its respective standard according to the guidelines laid down in the BIS 10500 (1991) and the result is multiplied by 100:

$$q_i = (C_i/S_i) \times 100$$

where  $q_i$  is the quality rating,  $C_i$  the concentration of each chemical parameter in each water sample in milligrams per liter,  $S_i$  is the Indian drinking water standard for each chemical parameter in milligrams per liter according to the guidelines of the BIS (1991).

For computing the WQI, the SI is first determined for each chemical parameter, which is then used to determine the WQI as per the following equation:

$$SI_i = W_i \times q_i$$

$$WQI = \sum SI_i$$

where  $SI_i$  is the sub-index of  $i$ th parameter,  $q_i$  the rating based on concentration of  $i$ th parameter,  $n$  is the number of parameters

**Table 5** Relative weight of chemical parameters

Chemical parameters	Indian Standard (BIS 1991)	Weight ( $w_i$ )	Relative weight $W_i = \frac{w_i}{\sum_{i=1}^n w_i}$
TDS	500	4	0.0784
pH	6.5–8.5	4	0.0784
Hardness	300	2	0.0392
Chloride	250	3	0.0588
Sulphate	200	4	0.0784
Nitrate	45	5	0.0980
Fluoride	1	4	0.0784
Calcium	75	2	0.0392
Magnesium	30	2	0.0392
Iron	0.3	4	0.0784
Copper	0.05	2	0.0392
Lead	0.05	5	0.0980
Chromium	0.05	5	0.0980
Cadmium	0.01	5	0.0980
		$\sum w_i = 51$	$\sum W_i = 1$

**Table 6** Water quality range and type of water

Range	Type of water
<50	Excellent
50–100	Good water
100–200	Poor water
200–300	Very poor water
>300	Water unsuitable for drinking

On the basis of WQI, types of water were determined and are given in Table 6. The computed WQI is given in Tables 7 and 8 that ranges from 155 to 574 and 154 to 510 for pre- and post-monsoon seasons, respectively. Spatial distribution maps for WQI (Fig. 11a, b) were created for both the seasons. In pre-monsoon season, overall water quality varies from poor to water unsuitable for drinking. High values (>300) were observed in north-western part and the central part indicating poor groundwater quality. While a different scenario is observed in post-monsoon season in terms of spatial distribution, water quality is further degraded in eastern part of the study area. North-western part of the study area shows a substantial variation in terms of WQI over the seasons.

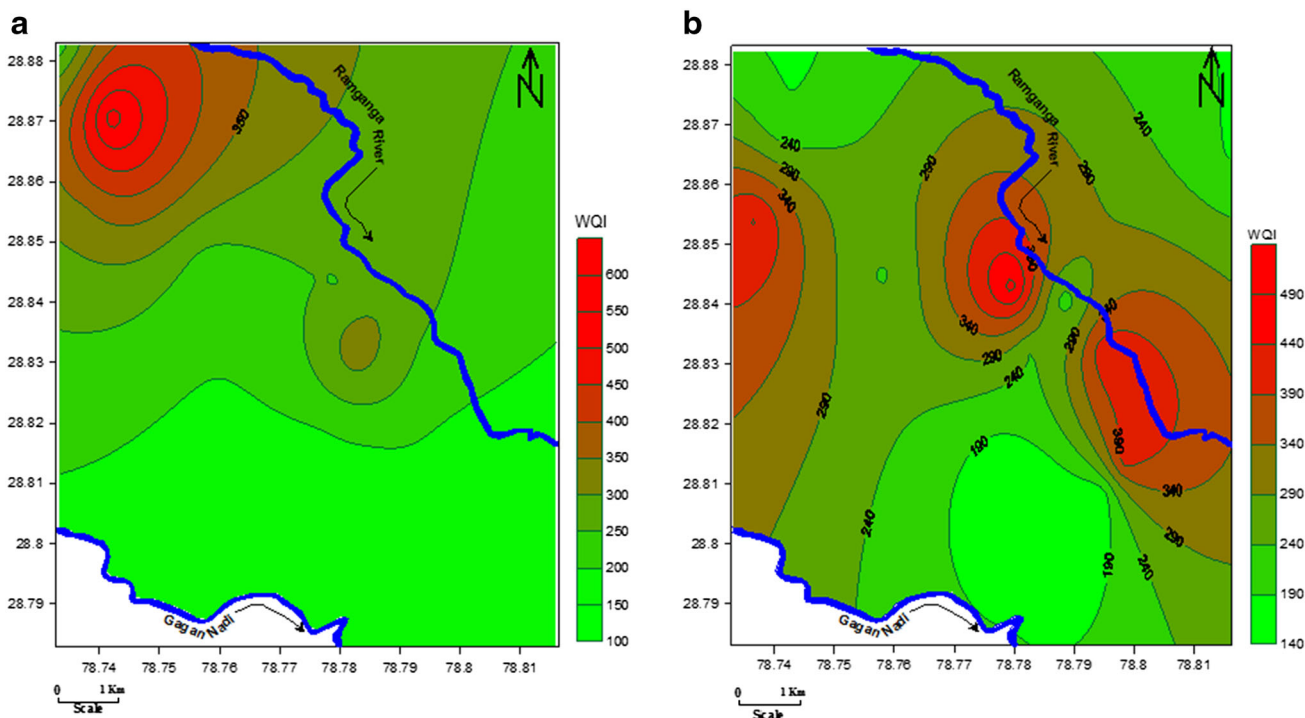
Chloride and EC were taken as pollution indicators and their respective maps were correlated with WQI map (Fig. 12a, b). From these figures it can be inferred that the locations which have high chloride concentration, high EC values also have high WQI values. This substantiate the validity of WQI map.

**Table 7** Calculation of WQI for individual water samples

S. no	PRM		POM	
1	222	Very poor water	201	Very poor water
2	574	Water unsuitable for drinking	196	Poor water
3	248	Very poor water	510	Water unsuitable for drinking
4	291	Very poor water	215	Very poor water
5	213	Very poor water	233	Very poor water
6	334	Water unsuitable for drinking	445	Water unsuitable for drinking
7	222	Very poor water	186	Poor water
8	333	Water unsuitable for drinking	240	Very poor water
9	235	Very poor water	428	Water unsuitable for drinking
10	179	Poor water	154	Poor water
11	155	Poor water	196	Poor water
12	179	Poor water	405	Water unsuitable for drinking
13	175	Poor water	167	Poor water
14	172	Poor water	172	Poor water

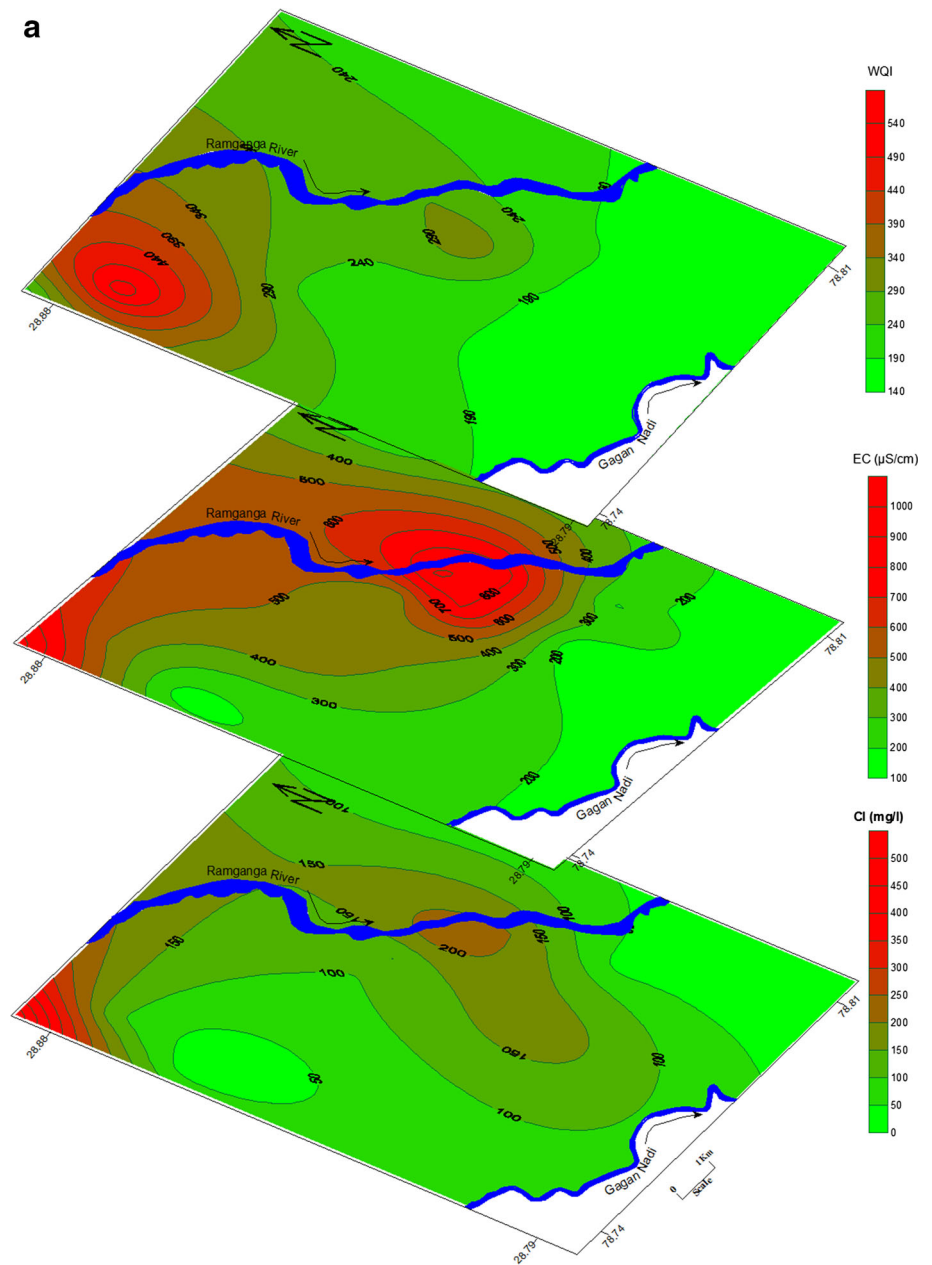
**Table 8** Water quality of the study area

Water quality	Pre-monsoon (2013)	Post-monsoon (2013)
Poor water quality	5 samples (36 %)	6 samples (43 %)
Very poor water quality	6 samples (43 %)	4 samples (29 %)
Water unsuitable for drinking purpose	3 samples (21 %)	4 samples (29 %)



**Fig. 11** Spatial distribution of WQI (a June 2013, b November 2013)

**Fig. 12** Correlation between Chloride, EC and WQI (a June 2013, b November 2013)

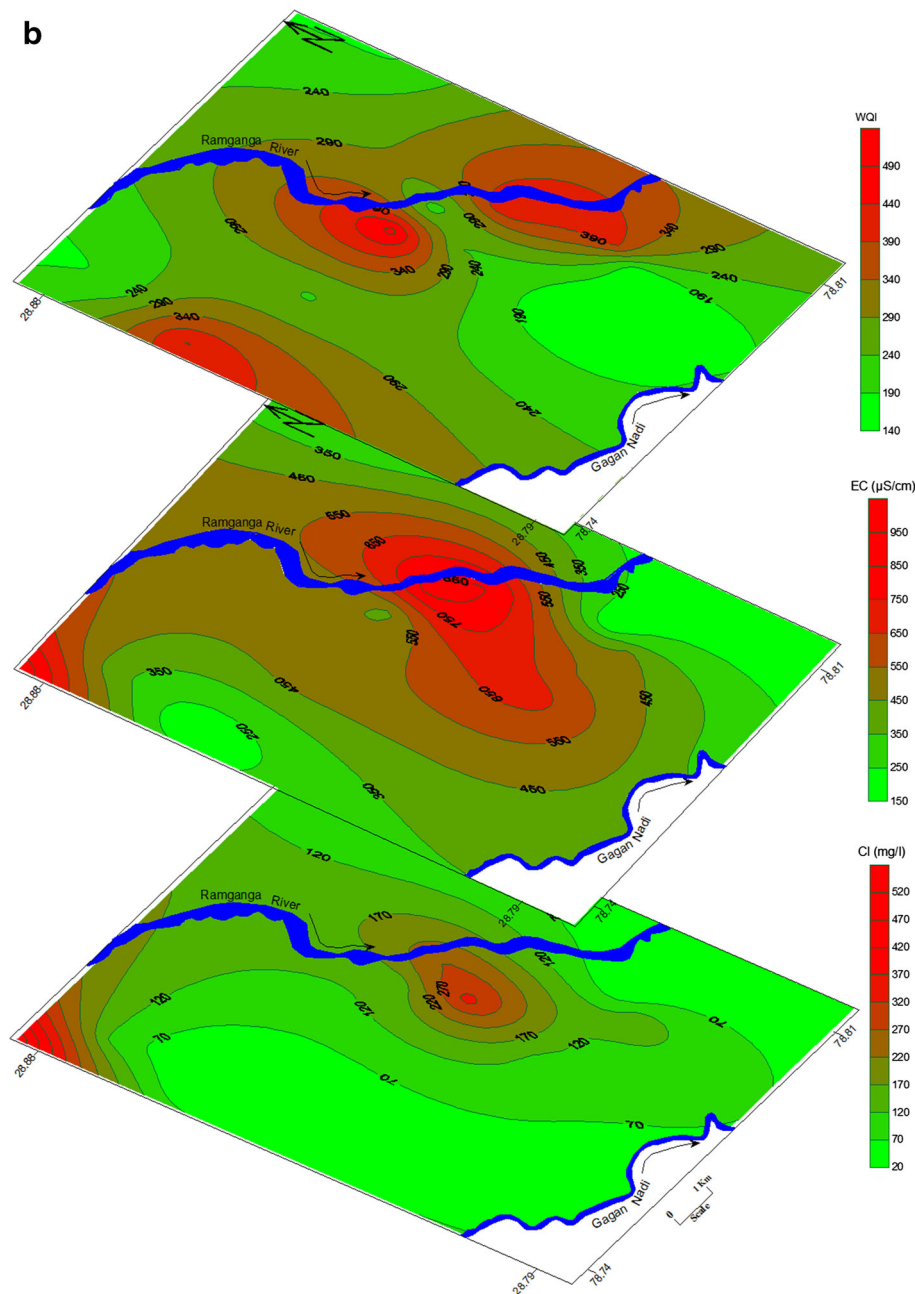


## Discussion

Moradabad city is a hub of many brassware industries. There are more than 500 small factories manufacturing brass, aluminium, steel and glass ware. These industries use brass (60 % Cu and 40 % Zn) and German silver (55 % Cu, 35 % Zn and 10 % Ni) for moulding purpose in making brassware items and other utensils. Cutting, grinding, scraping, polishing, melting of steel, are the main activities occurring in these industries. These industries produces a wide variety of effluents containing As, Cd, Co, Cr, Hg, Mn, Ni, Pb, Cu, Zn, Sn and Ti and are thus responsible for the higher concentration of trace elements

in the area (Tripathi et al. 1990; Mahima et al. 2013). Burning of e-waste in the city along the bank of river Ramganga leads to the emission of various toxic metals in the environment (Pal et al. 2014). Coal combustion in various industries and high traffic also introduce trace elements in the groundwater system. These metals are leached down with the groundwater flow direction and thus increase the concentration of metals in the area. Presence of landfill in the south eastern part of the city is also responsible for the elevated concentrations of ions in the area. This is well supported by the WQI maps that the industrial locations as well as landfill site are characterized by high WQI range.

Fig. 12 continued



## Conclusion

The impact of urbanization can be seen on the groundwater quality of the study area which is attributed to population growth, industrialization, and change in land use pattern. Groundwater is acidic to slightly alkaline nature. The order of abundance of major ions in pre-monsoon is  $\text{Na} > \text{Mg} > \text{Ca} > \text{K}$ ;  $\text{HCO}_3 > \text{SO}_4 > \text{Cl} > \text{NO}_3 > \text{F}$  and  $\text{Na} > \text{Ca} > \text{Mg} > \text{K}$ ;  $\text{HCO}_3 > \text{SO}_4 > \text{Cl} > \text{NO}_3 > \text{F}$  in post-monsoon season. Order of abundance for trace elements in pre-monsoon is  $\text{Fe} > \text{Al} > \text{Zn} > \text{Cu} > \text{Pb} > \text{Se} > \text{Cr} > \text{Ni} > \text{As} > \text{Cd} > \text{Co}$  and  $\text{Fe} > \text{Zn} > \text{Pb} >$

$\text{Se} > \text{Cu} > \text{Cr} > \text{As} > \text{Ni} > \text{Cd} > \text{Co}$  in post-monsoon season. Groundwater facies identified from Piper Trilinear plot in pre-monsoon season is  $\text{Na}-\text{Cl}-\text{SO}_4$  type and  $\text{Na}-\text{HCO}_3$  in post-monsoon season. Nitrate, bicarbonate, chloride, sulphate and sodium represent the ions contributing from the anthropogenic activities e.g. leaching of nitrate from the sewerage lines, domestic waste etc. Trace elements (Al, Cr, Fe, Pb, Se, Cu, As, and Cd) are present in concentration above permissible limits in the groundwater of the study area. As far as sources of these elements are concerned, it is anticipated that urbanization and population growth, expansion of industries, could be the reason.

The influence of anthropogenic and geogenic processes on groundwater samples is assessed by SiO<sub>2</sub> with Cl and TDS plots which suggests that alteration in meteoric signature of groundwater quality is combined effect of anthropogenic and geogenic processes. Water quality index maps indicate poor groundwater quality. In general groundwater quality is a combined effect of variation in rainfall recharge, geochemical reaction, land use pattern. Various anthropogenic and geogenic processes are playing role in modifying the chemical characteristics of the groundwater of the study area.

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