



Groundwater quality assessment of Allahabad smart city using GIS and water quality index

H. K. Pandey¹ · Vivek Tiwari² · Saurabh Kumar¹ · Aniket Yadav¹ · S. K. Srivastava³

Received: 2 October 2018 / Accepted: 24 January 2020 / Published online: 10 March 2020
© Springer Nature Switzerland AG 2020

Abstract

Groundwater quality plays a very important role in groundwater protection as well as demarcation of the groundwater depleted area which may be attempted for its improvement and conservation. An effort has been made to comprehend the water quality of Allahabad city with the help of groundwater sampling, their chemical analysis, and synthesis of results in GIS framework. The assessment of physiochemical parameters of groundwater samples for drinking purpose has been made using Water Quality Index and Geographic Information System. Spatial distribution of pH, electrical conductivity, total dissolved solids, fluoride, iron, total alkalinity, total hardness, chloride, sulphate, sodium, potassium, calcium, magnesium, bicarbonate, and nitrate content of groundwater samples collected from 12 locations and studied for pre-monsoon (May 2016) and post monsoon (Nov 2017) periods has been assessed using Arc-GIS. Water quality maps of pre-monsoon period reveal that 4.23% area is falling under good, 74.82% under moderate, and 12.12% under poor and 0.66% under very poor category while water quality maps for post monsoon period reveal that the 40.33% of area falls under good, 58.89% area under moderate and 0.77% under poor water quality. The observed values of various physiochemical parameters of water samples were also compared with standard values recommended by IS 10,500:2012. It is observed that depth to water has positive correlation with TDS, electrical conductivity, and hardness. The extent of pollution occurred in the city is due to over exploitation of groundwater, urbanization, and anthropogenic activities.

Keywords WQI · GIS · Allahabad · TDS

Introduction

Environmental protection and water quality preservation are one of the essential tasks for each person in the world (Alban 2014). Global urbanization is causing serious issue mainly to the quality of water coming from different sources which are being collected in large water bodies (Alban et al. 2016). Water is the most important factor for shaping the land surface and regulating the climate. It is one of the most important natural resource that profoundly influence the entire ecosystem. Due to rapid industrialization and urbanization, the demand of groundwater has increased many folds

in the last few decades which in turn has created stress on water resources particularly groundwater. Poor groundwater quality also leads to human health hazards and consumes lot of expenses on treatment of different kind of water borne diseases. Once the groundwater is polluted, it is very difficult to rehabilitate it. The rapid pace of agricultural development, industrialization, and urbanization has also resulted in the over exploitation and contamination of ground water resources in different parts of the country. This has resulted in various adverse environmental impacts which affects the long-term sustainability of groundwater resource. Most of the population in India is dependent on groundwater for drinking purpose. The latest estimates of Central Pollution Control Board show about 29,000 million liter/day of wastewater is generated from Class-I and Class-II towns out of which about 45% is generated from 35 Metro cities alone (Mangukiya et al. 2012). The groundwater quality data are very important and crucial for decision regarding the quality assessment and its treatment. There has been considerable advancement in classification of groundwater particularly

✉ H. K. Pandey
hkp@mnnit.ac.in

¹ Civil Engineering Department, MNNIT, Allahabad, India

² Institute of Agriculture Science, BHU, Varanasi, India

³ CGWB, Ministry of Jal Shakti, Govt. of India, Faridabad, India

based on the principle of WQI (Smith 1990; Dojlido et al. 1994; Stambuk—Giljanovic 1999; Pesce and Wunderlin 2000; Sargaonkar and Deshpande 2003; Kannel et al. 2007; Nasirian 2007; Singh et al. 2008). The sub-index development and aggregation function are used as principle components of Water Quality Index. The WQI reflects the overall condition of water in different environmental conditions.

GIS is being recognized as a powerful tool in addressing the diversified issues and managing geographical information in holistic manner without losing the spatio-temporal variability which are often critical in assessment and decision making (Mtetwa and Schutte 2002; Environmental Systems Research Institute (ESRI) 1996;). The main objective of the present study is to assess the groundwater quality for drinking purpose using Water quality index (WQI) and Geographic Information System (GIS). To achieve the aim of the present study, 15 important parameters such as pH, electrical conductivity(EC), total hardness (TH), total dissolved solid (TDS), alkalinity, sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), nitrate (NO_3^-),

bicarbonate (HCO_3^-), chloride (Cl^-), sulphate (SO_4^{4-}), fluoride (F^-), and iron (Fe), were considered for the assessment of groundwater quality.

Study area

Allahabad also known as Prayagraj is an ancient and one of the most religious city of India. The area of the city is 70.5 sq km. The study area is limited by altitude of $25^0 27'$ to $25^0 45'$ and longitude of $81^0 24'$ to $81^0 50'$ with an average altitude of 98.0 m amsl in the southern part Uttar Pradesh, India (Fig. 1). Although the block encompassing the Allahabad city is categorized as safe on the basis of resource estimation, but the city area itself is under significant quantitative and qualitative stress. The ground water draft has increased many folds in the city while natural recharge has been reduced drastically. During the last five years, the decline of water level of tube wells/ hand pumps in the city area of Allahabad has been recorded up to 2 m (Singh et al. 2014).

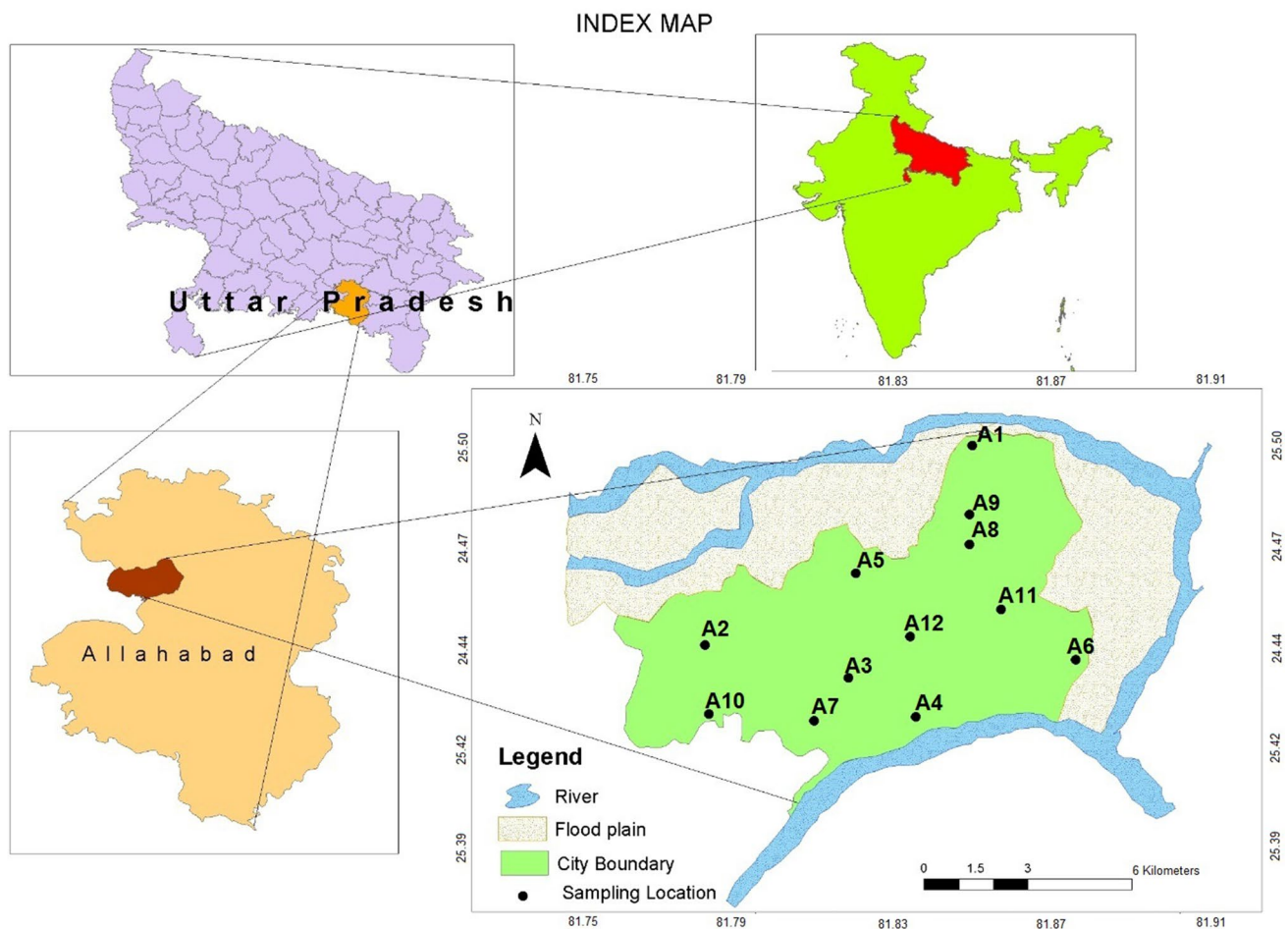


Fig. 1 Study Area

Material and methodology

The study involves the detailed laboratory and field investigations including collection of groundwater samples through handpumps/dugwells from different locations. Twelve numbers of groundwater samples were collected from twelve locations in the study area as per the standard methods prescribed by APHA (1995). The groundwater sample location points have been marked on the geo-reference map using Global Positioning System (GPS). Groundwater sample location points are shown in Fig. 2. Under this study, the fifteen groundwater quality parameters were analyzed using standard methods prescribed by APHA (1995). The statistical analysis of the analyzed groundwater quality is given in Table 1.

Groundwater quality

pH

pH indicates the hydrogen ion concentration in water. Water in its purest form has a neutral pH of 7.0. As per the Bureau of Indian Standards (BIS 2012), the pH is required to be in the

Table 1 Statistical analysis of analysed physico-chemical groundwater quality parameters in study area

Parameter	Maximum	Minimum	Mean	Standard deviation
pH	7.80	6.80	7.50	0.29
EC	1512.31	533.85	943.08	271.24
Hardness	516.00	268.00	368.33	64.78
TDS	983.00	347.00	613.00	176.31
Alkalinity	536.00	284.00	416.67	71.63
Na	78.30	63.70	69.78	4.54
K	6.91	1.75	3.62	1.36
Calcium	96.00	60.00	74.33	10.19
Magnesium	137.10	57.30	79.93	20.70
Nitrate	19.40	0.14	7.90	5.17
Bicarbonate	516.00	268.00	370.00	65.14
Chloride	137.00	57.00	99.92	26.17
Sulphate	294.30	59.90	123.39	68.21
F	1.08	0.17	0.65	0.30
Fe	1.67	0.46	0.88	0.44

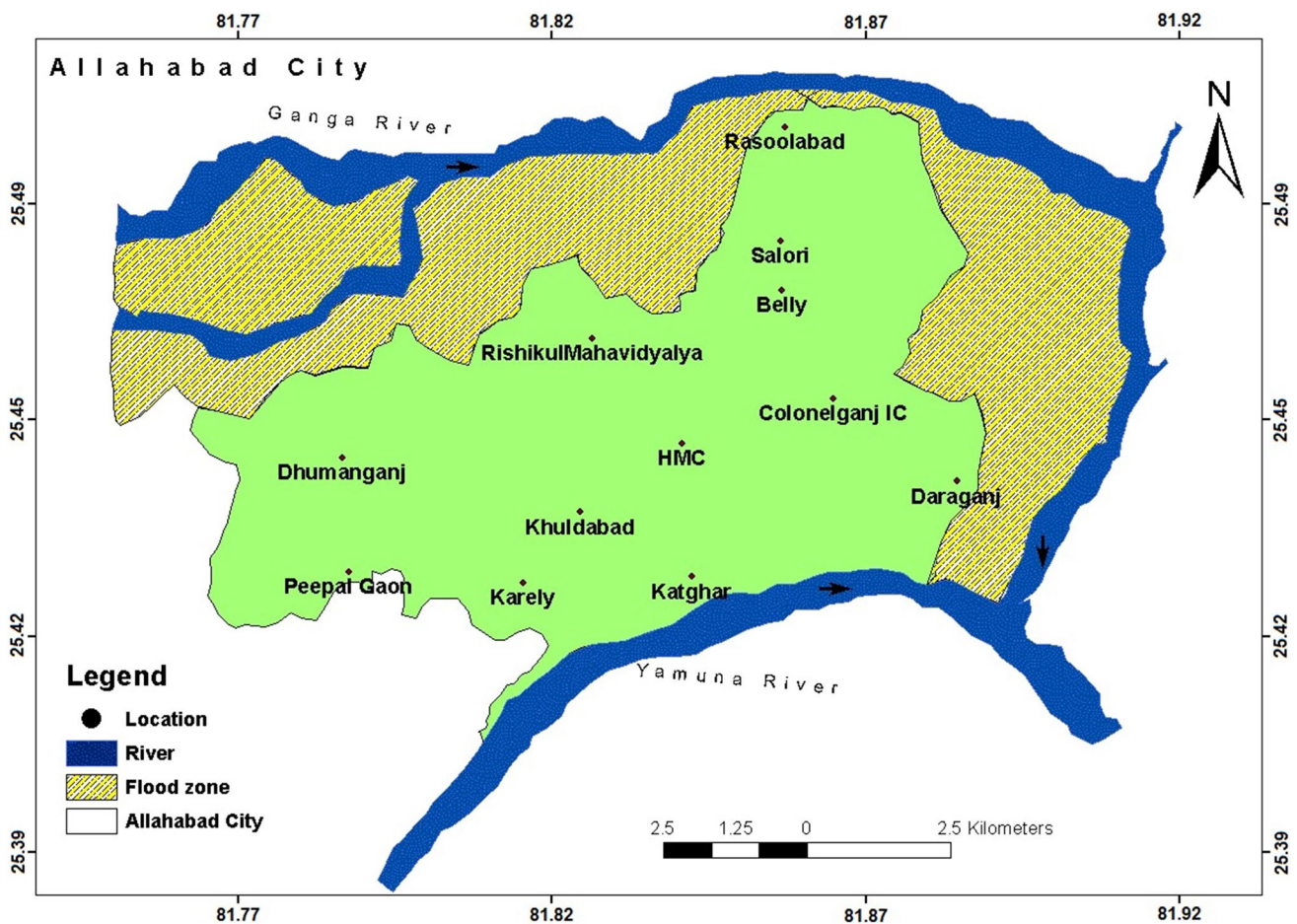


Fig. 2 Location map of groundwater sampling points

range of 6.5–8.5 for drinking purpose. In the current study, the pH ranges between 6.8 (minimum) and 7.8 (maximum) which shows that it is within the permissible limit (Fig. 3).

Total dissolved solids

TDS is mainly due to soluble inorganic salts and organic matter. The major constituent of TDS in water is calcium, magnesium, sodium, and potassium and the anions carbonate, bicarbonate, chloride, and sulphate. According to the BIS (BIS 2012), the ideal TDS for drinking water is below 500 mg/l and the maximum permissible limit is 2000 mg/l. In the current study, it was found between 347 and 983 mg/l (Fig. 4).

Electrical conductivity

Electrical conductivity (EC) is a measurement of the dissolved material in an aqueous solution; higher the dissolved material in a water sample, the higher the EC will be in that

material. Electrical conductivity is strongly correlated with sodium. As per BIS the permissible limit for EC is 3000 $\mu\text{S}/\text{cm}$ at 25 °C considering the factor for conversion of EC into TDS. In the study area, it ranges 533.85–1512.31 $\mu\text{S}/\text{cm}$. (Fig. 5).

Hardness

Total hardness arises in water due to the presence of calcium and magnesium. In general, hard waters originate in areas where the top soil is thick and limestone formations are present (Arumugam 2010). In the present study hardness ranges from 268 to 516 mg/l (Fig. 6) which are within the permissible limits (600 mg/l).

Alkalinity

Alkalinity in water is due to the presence of carbonate, bicarbonate, and hydroxide ions. The desirable limit of total

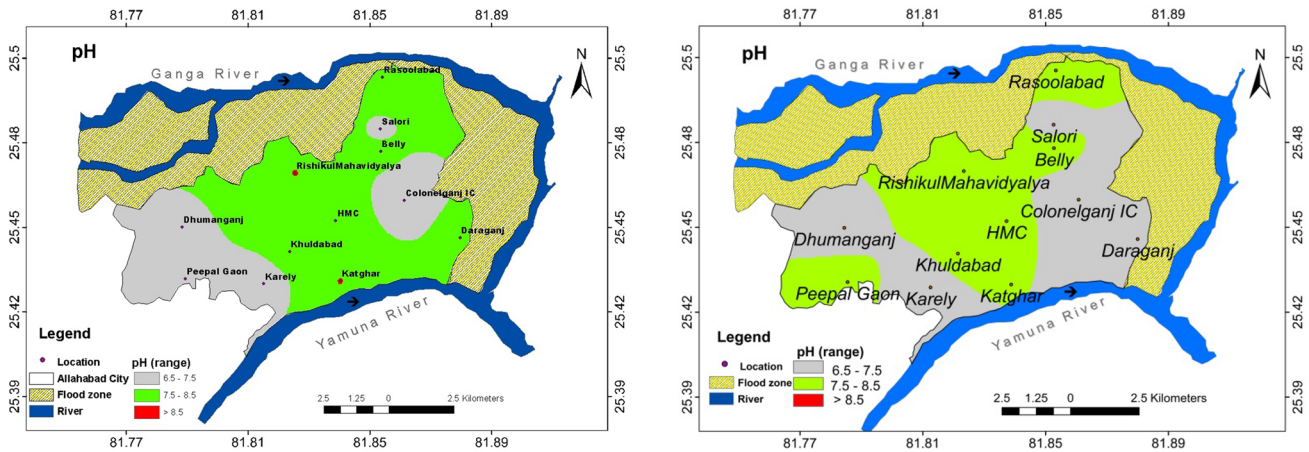


Fig. 3 Spatial distribution of pH during pre and post Monsoon

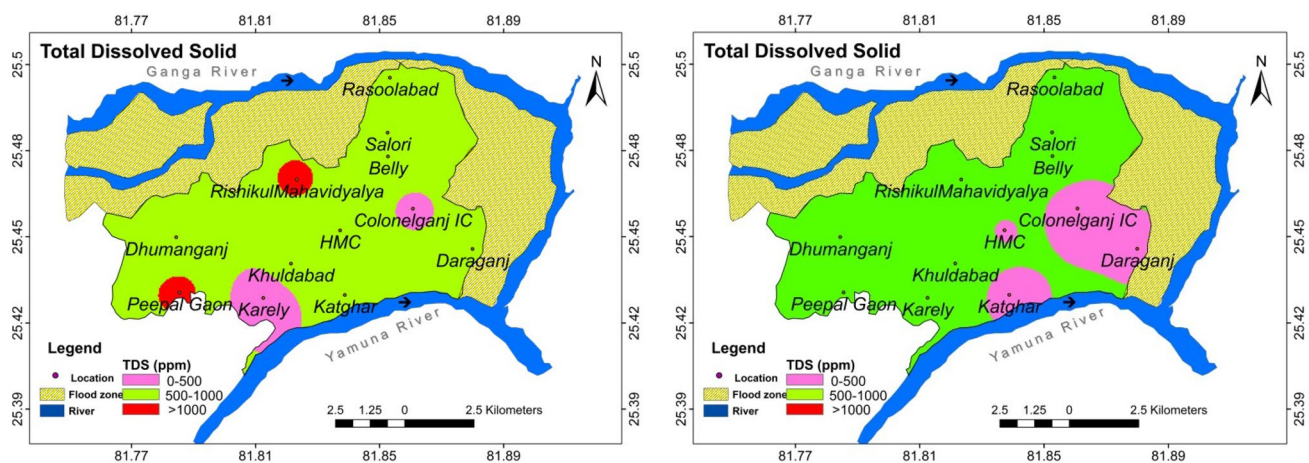


Fig. 4 Spatial distribution of TDS during pre and post Monsoon

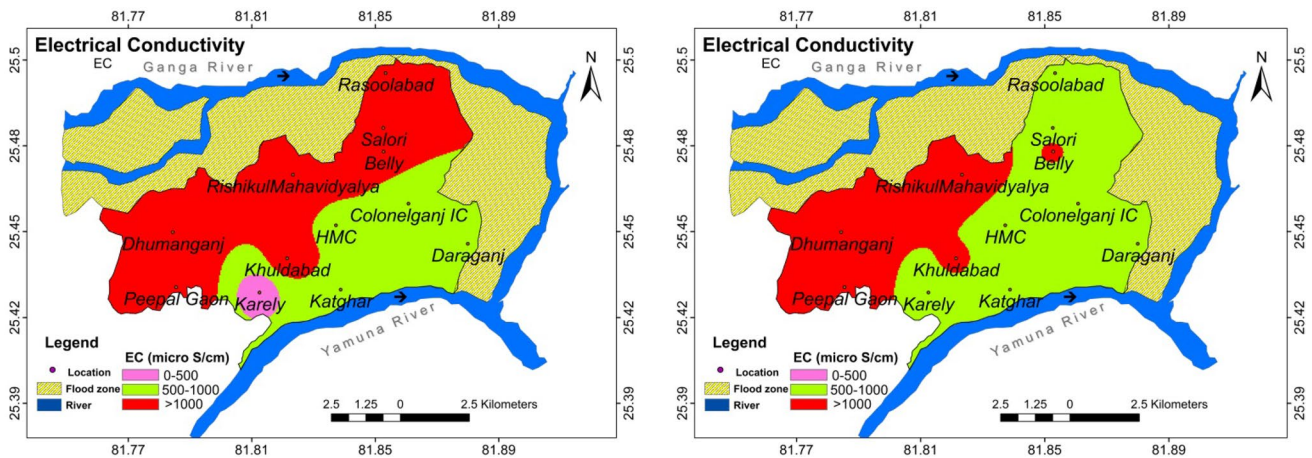


Fig. 5 Spatial distribution of EC during pre and post Monsoon

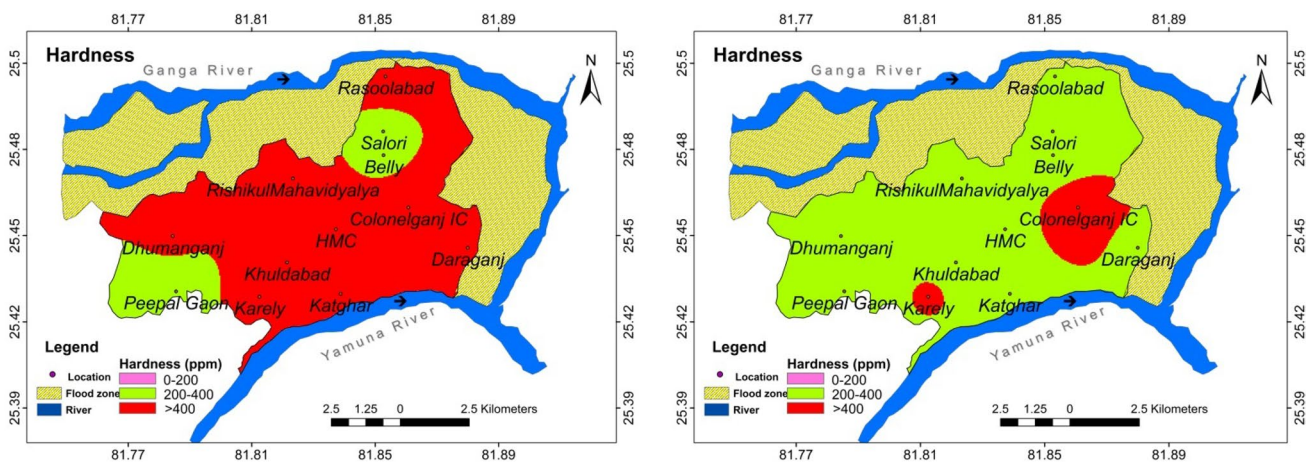


Fig. 6 Spatial distribution of hardness during pre and post Monsoon

alkalinity in drinking water is 200 mg/l. beyond this value, water tastes unpleasant, whereas in the absence of alternate water source, alkalinity upto 600 mg/l is permissible. In the present study, the alkalinity ranges between 284 and 536 mg/l which lies within the limits (Fig. 7).

Sulphate

Weathering and dissolution of gypsum, iron sulphides, and other sulphur compounds are the main sources of sulphate (SO_4^{2-}) in groundwater. It is commonly observed in mine water and industrial dumping sites. In the study area, it ranges from 59.90 to 294.30 mg/l which is under permissible limit of 400 mg/l (Fig. 8).

Chloride

The higher concentration of chlorine in water makes it hazardous to human health which is subjected to laxative

effects (Anitha et al. 2011; Sadat-Noori et al. 2014). The chloride concentration ranges from 57 to 137 mg/l in the present study (Fig. 9) which is within permissible limit of 1000 mg/l (Table 2).

Nitrate

The major causative source of nitrate is anthropogenic. Nitrate concentration causes the blue baby syndrome, gastric cancer, thyroid disease and diabetes beyond the permissible limit (45 mg/l) as per BIS 2012 (Krishna Kumar et al. 2011; Kumar et al. 2014). Nitrate concentration in the study ranges between 0.14 and 19.40 mg/l (Fig. 10) which is within desirable limit.

Calcium

Calcium is present in divalent cations. Due to their higher concentration, the water causes abdominal ailment and encrustation (Kumar et al. 2014). In the current study, the

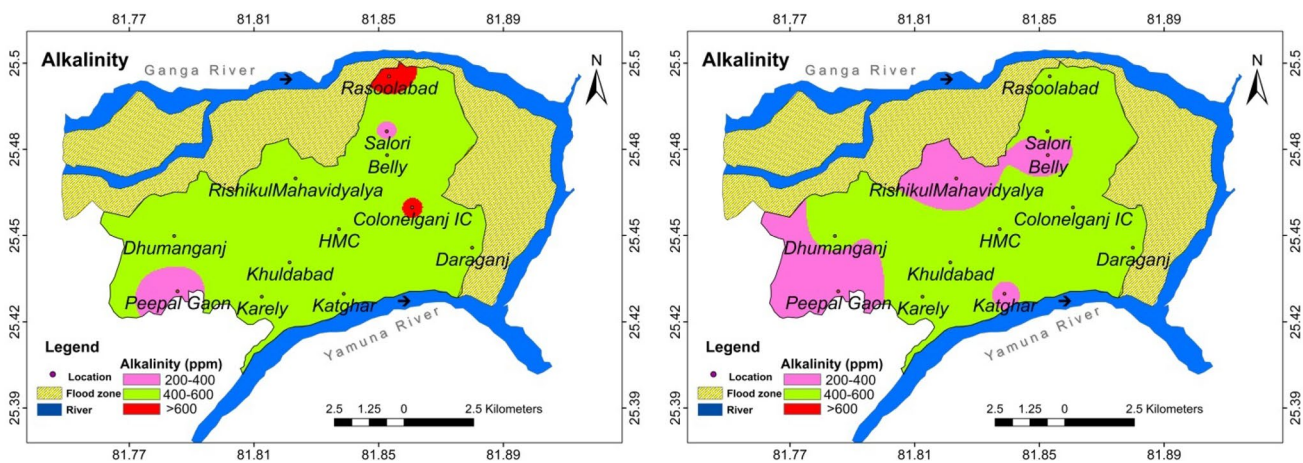


Fig. 7 Spatial distribution of alkalinity during pre and post Monsoon

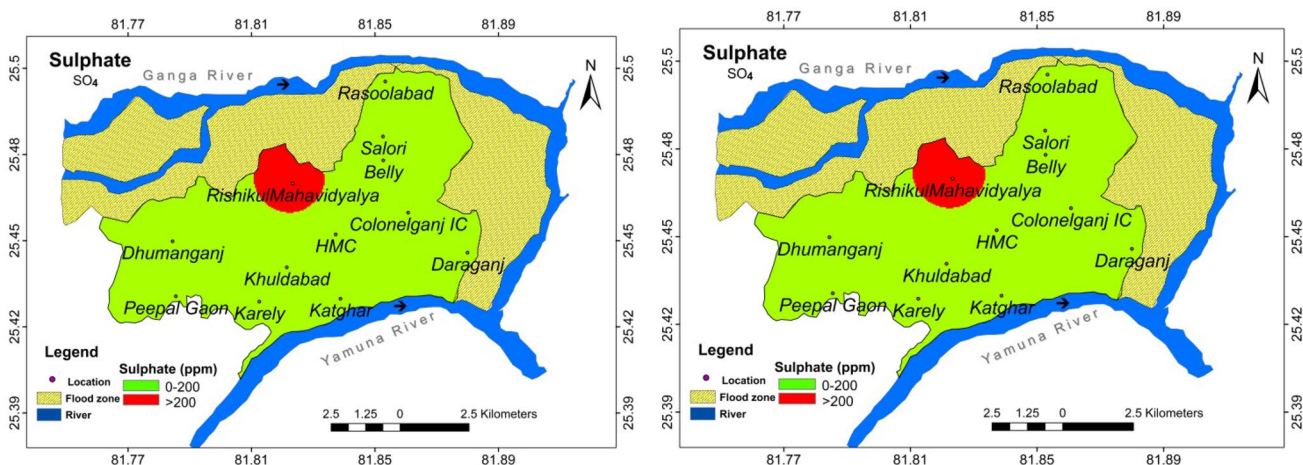


Fig. 8 Spatial distribution of sulphate during pre and post Monsoon

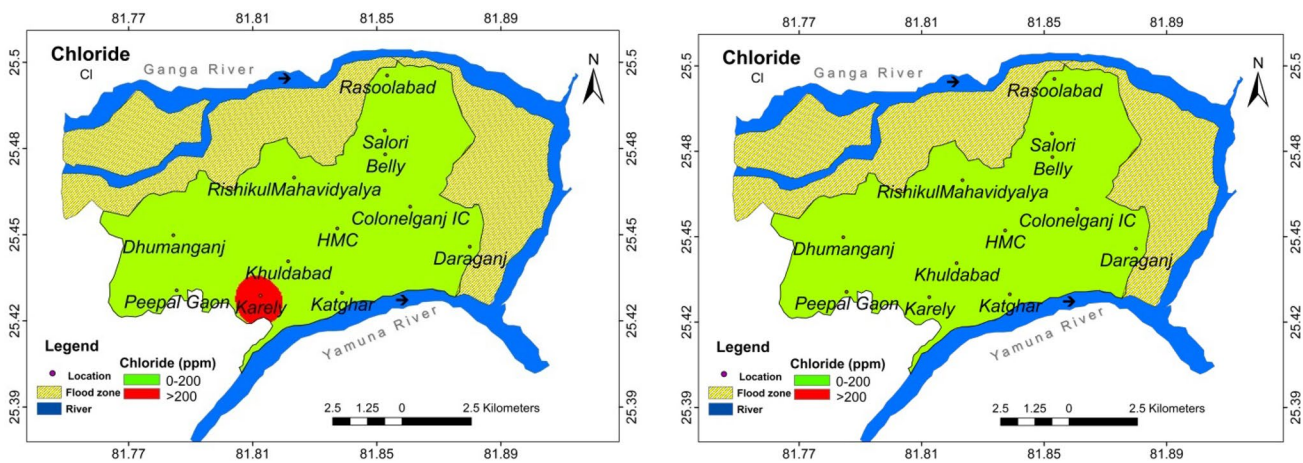


Fig. 9 Spatial distribution of chloride during pre and post Monsoon

calcium concentration ranges from 60 to 90 mg/l (Fig. 11) which are under permissible limit of 200 mg/l.

Potassium

Potassium is common in many rocks. These rocks are relatively soluble; therefore the concentration of potassium in ground water increase over the period. In the present study, it varies from 1.75 to 6.91 mg/l (Fig. 12) which is found to be within permissible limit of 12 mg/l.

Sodium

Groundwater is characterized by the common presence of sodium because soil/ rock contains sodium which is soluble in nature. The permissible limit of sodium is 200 mg/l and in present study it is found in the range 63.70–78.30 mg/l (Fig. 13). Excess intake of sodium through drinking water may be responsible for hypertension, heart disease and kidney problems.

Fluoride

The main source of fluoride in water is geogenic. There are many harmful effect of fluoride in either cases i.e. very low doses of fluoride (<0.6 mg/l) in water promote tooth decay. However, when consumed in higher doses (> 1.5 mg/l), it leads to dental fluorosis or mottled enamel. Although, excessively high concentration (> 3.0 mg/l) of fluoride may lead to skeletal fluorosis (Raju 2009). In the study, the fluoride concentration ranges from 0.17 to 0.65 mg/l (Fig. 14).

Iron

Extremely common, iron (Fe) is dissolved from practically all rocks and soils. Groundwater of acidic character

is corrosive, thus dissolve iron and increase its concentration flowing through pipes, pumps, and other equipments. In the present study, the iron ranges from 0.46 to 1.67 mg/l (Fig. 15) which exceeds the permissible limit of 1 mg/l.

Magnesium

It comes from some rocks and soils, and not so common as iron, manganese (Mg) has many of the objectionable features. In the present study, magnesium contents ranges from 57.30 to 137.10 mg/l (Fig. 16) under the permissible limit (30–100 mg/l). The oxidized form of manganese causes dark brown or black stains.

Bicarbonate

It comes in action of carbon dioxide in water on carbonate rocks such as limestone and dolomite, bicarbonate (HCO_3^-) produces an alkaline environment. It ranges in the present study from 268 to 516 mg/l (Fig. 17) which is within the permissible limit of 600 mg/l.

Water quality index (WQI)

In the present study, all the 15 parameters were selected to calculate the water quality index. The WQI has been calculated using the standards of drinking water quality recommended by World Health Organization (WHO 1992), Bureau of Indian Standard (BIS) and Indian Council for Medical Research (ICMR 1975). The weighted arithmetic index method (Brown et al. 1972) has been used for the calculation of WQI of the water. The following steps are involved in WQI determination.

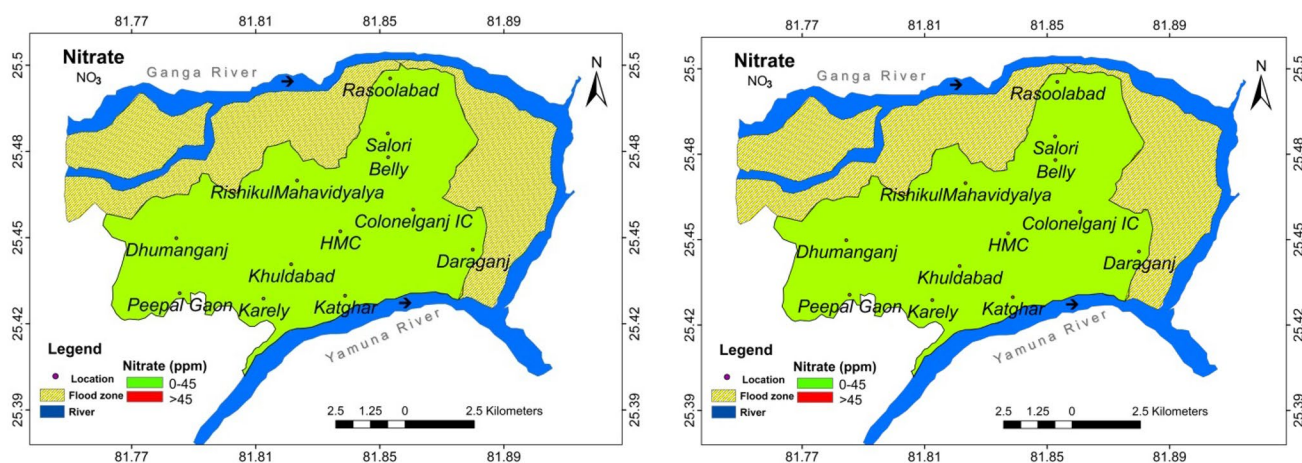


Fig. 10 Spatial distribution of nitrate during pre and post Monsoon

Table 2 Correlation matrix between various groundwater quality parameters (author calculations)

	pH	TDS	Nitrate	F	Fe	Na	K	Sulphate	Alkalinity	Hardness	Calcium	Magnesium	Chloride	Bicarbonate
pH	1													
TDS	0.375	1												
Nitrate	-0.389	-0.239	1											
F	0.517	.703*	-0.038	1										
Fe	-0.136	0.064	0.080	-0.219	1									
Na	0.523	-0.039	-0.255	-0.035	0.167	1								
K	0.436	0.354	-0.252	0.514	-0.352	0.316	1							
Sulphate	0.382	0.268	-0.270	0.030	-0.212	-0.021	0.015	1						
Alkalinity	0.010	-0.356	-0.248	-0.201	-0.330	0.427	0.013	-0.043	1					
Hardness	-0.095	-0.504	-0.322	-0.374	-0.463	0.250	-0.028	0.037	0.828**	1				
Calcium	0.340	0.008	0.125	0.113	-0.170	0.621*	0.005	-0.141	0.583*	0.396	1			
Magnesium	0.527	0.432	-0.044	0.453	-0.341	0.087	0.223	0.794**	0.077	-0.072	0.141	1		
Chloride	-0.339	-0.670*	0.475	-0.264	0.347	0.081	-0.372	-0.339	0.116	0.060	-0.032	-0.286	1	
Bicarbonate	-0.095	-0.504	-0.322	-0.374	-0.463	0.250	-0.028	0.037	0.828**	1.0000**	0.396	-0.072	0.060	1

Weightage factor (Wi)

Firstly, we assigned weight (w_i) to the parameters in according to its significance in the drinking water quality. The weightage factor is calculated by following formula.

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

where, W_i is the relative weight, w_i is the weight of each parameter and n is the number of parameter. The assigned weight for each parameter is given in Table 3.

Calculation of quality rating/ sub index (q_n)

Quality rating is calculated by the following equation:

$$(Sub\ index)q_n = \frac{(Estimated\ value - ideal\ value)}{(Standard\ value - ideal\ value)} \times 100$$

(Let there be n water quality parameters and quality rating or sub index (q_n) corresponding to n th parameter is a number in the polluted water with respect to its standard permissible value).

q_n = Quality rating for the n th Water quality parameter.

WQI calculation

For calculating the WQI, sub-index is first calculated for each parameter using the following equation:

$$SI_i = q_i \times w_i$$

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

The overall water quality-index (WQI) was figured by adding together each sub-index value of each groundwater sample as follows (Ramakrishnaiah et al. 2009; Sadat-Noori et al. 2014):

$$WQI = \sum SI_i$$

Computed WQI values were classified into 5 categories good, moderate, poor, very poor and not suitable for drinking as given in Table 4.

Result and discussion

The seasonal variation of the chemical parameters was evaluated and the order of abundance of the ions was determined. Variation in groundwater quality was observed during both the periods of the study i.e. pre-monsoon and post-monsoon period in the year 2016–2017. It is found in the study that

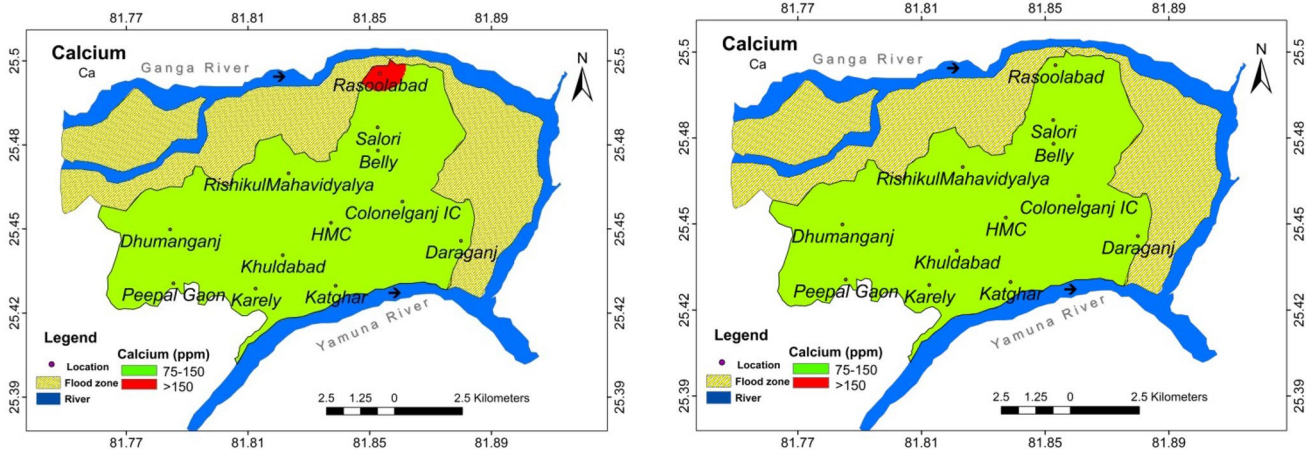


Fig. 11 Spatial distribution of calcium during pre and post Monsoon

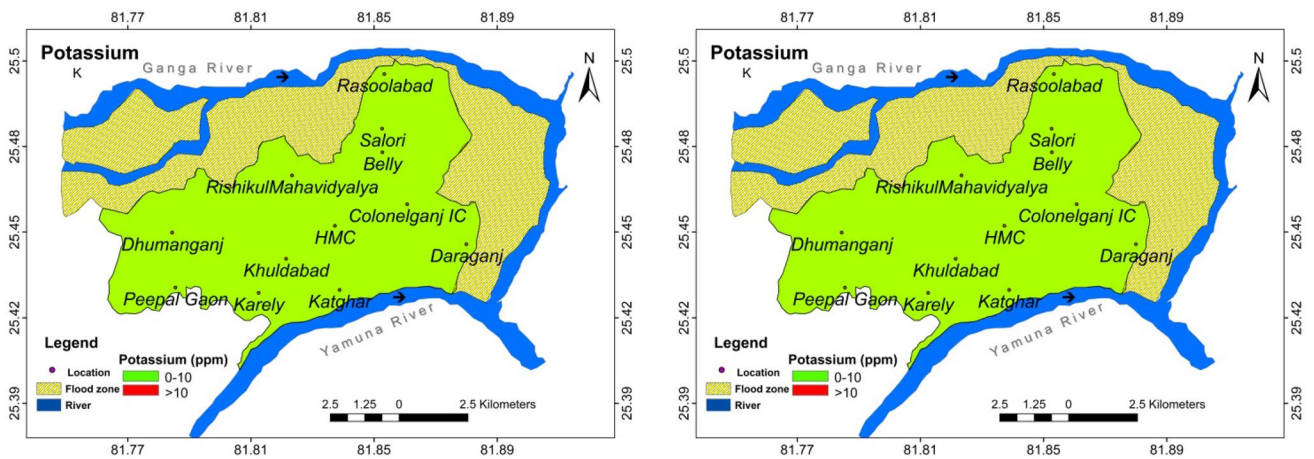


Fig. 12 Spatial distribution of potassium during pre and post Monsoon

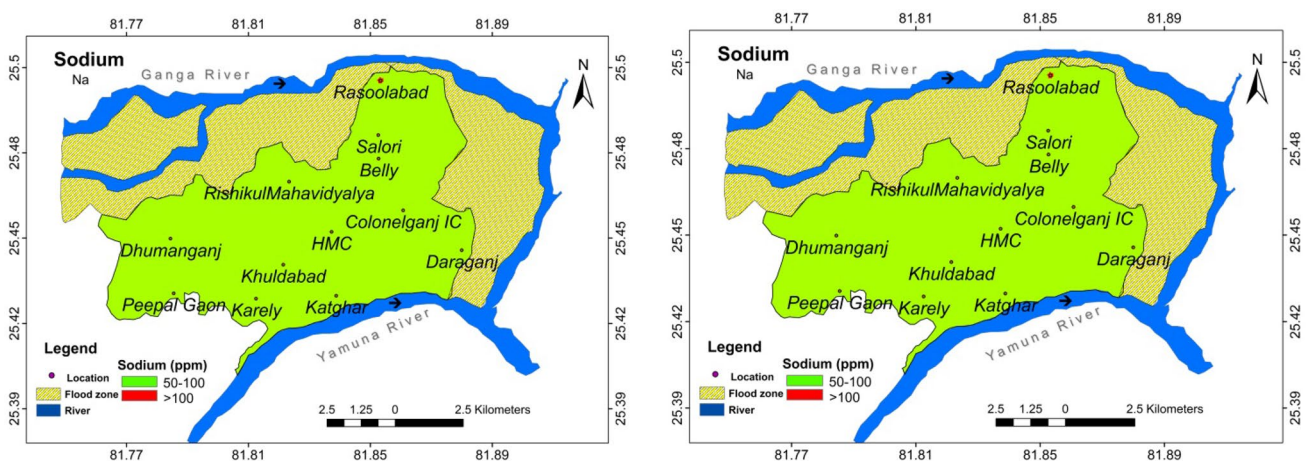


Fig. 13 Spatial distribution of sodium during pre and post Monsoon

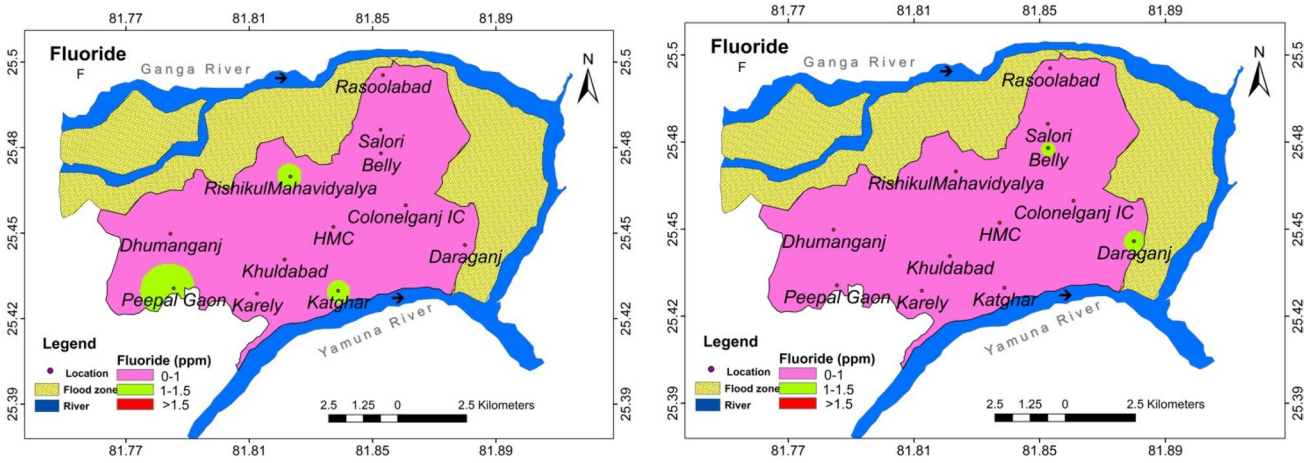


Fig. 14 Spatial distribution of TDS during pre and post Monsoon

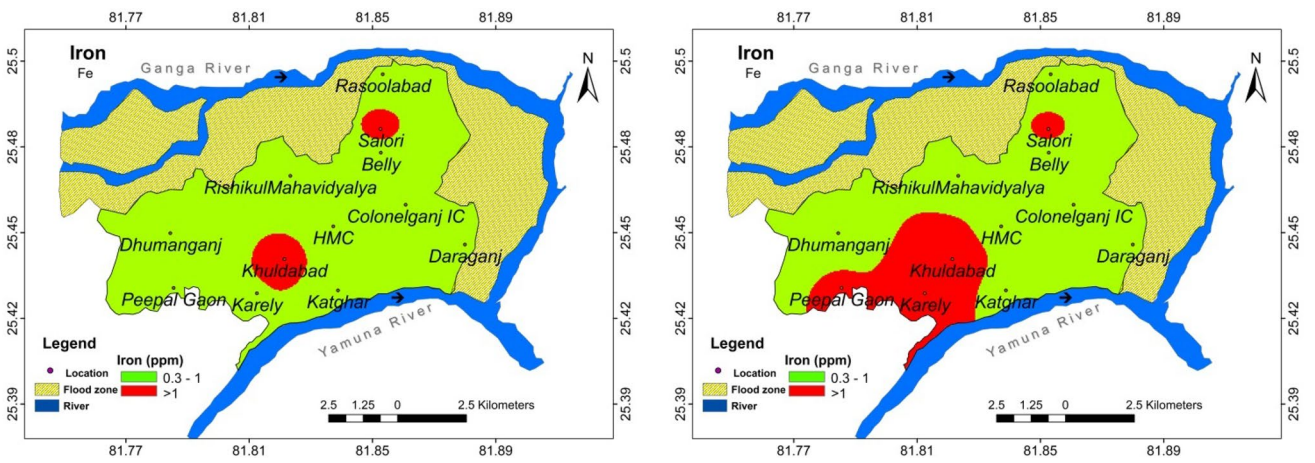


Fig. 15 Spatial distribution of iron during pre and post Monsoon

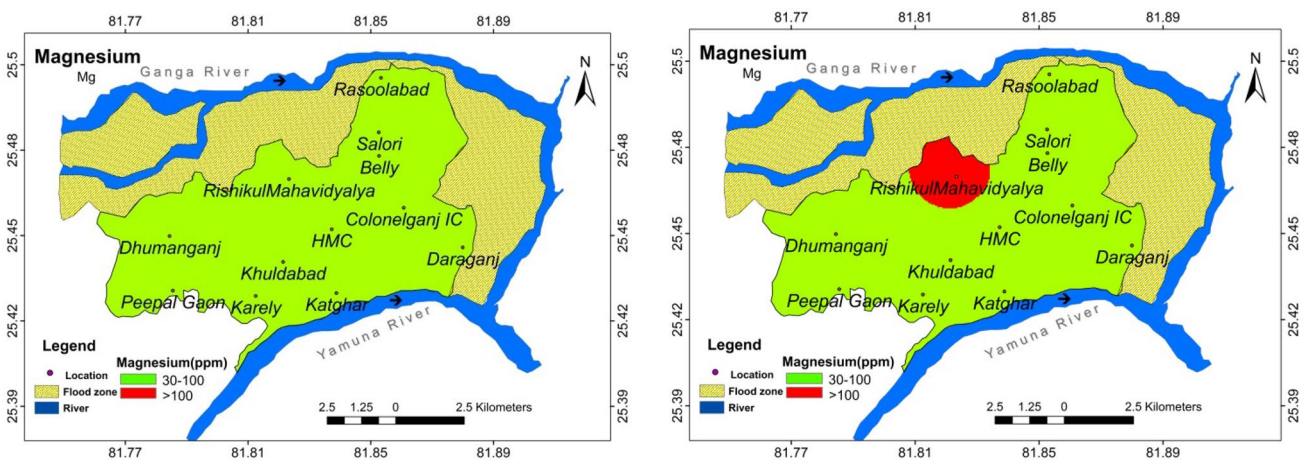


Fig. 16 Spatial distribution of magnesium during pre and post Monsoon

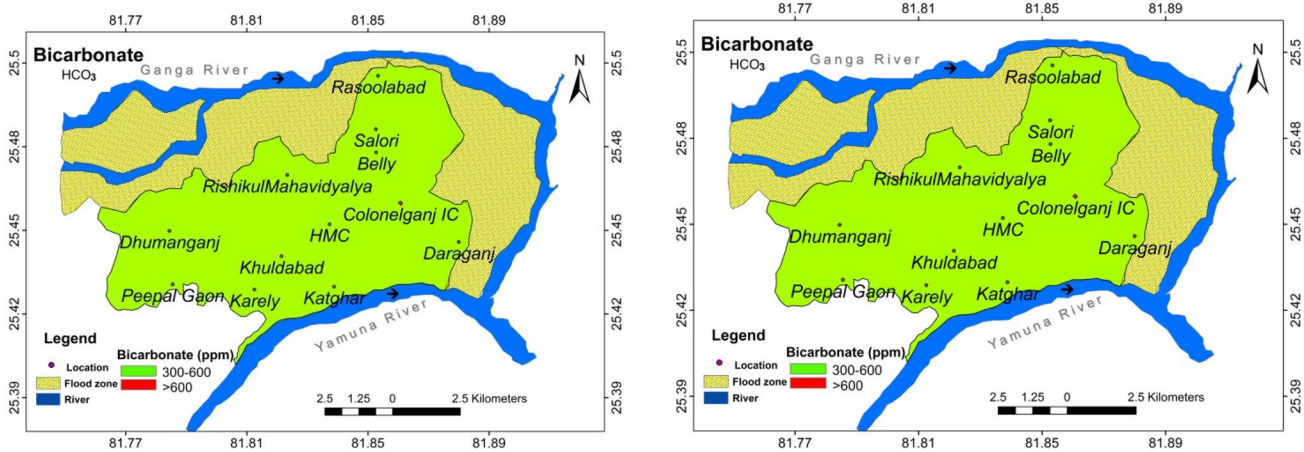


Fig. 17 Spatial distribution of bicarbonate during pre and post Monsoon

Table 3 Weight (*w_i*) and relative weight of (*W_i*) each parameter

Parameter	Permissible limit	Weightage (<i>w_i</i>)	Relative weight (<i>W_i</i>)
pH	8.5	2	0.083
EC	3000	1	0.042
Hardness	600	1	0.042
TDS	2000	2	0.083
Alkalinity	600	1	0.042
Na	200	1	0.042
K	12	1	0.042
Calcium	200	1	0.042
Magnesium	100	1	0.042
Nitrate	45	2	0.083
Bicarbonate	600	1	0.042
Chloride	1000	1	0.042
Sulfate	400	2	0.083
F	1.5	4	0.167
Fe	1	3	0.125
		$\sum W_i = 27$	$\sum W_i = 1$

the magnesium concentration beyond permissible limit in water sample of Rishikul Mahavidyalay (149.7 mg/l) and Belly (111.8 mg/l) (Fig. 16) during pre-monsoon phase. The study reveals that the iron concentration is beyond the permissible limit of 1 mg/l throughout the study area. The alkalinity value was found beyond permissible limit at two locations i.e. at Rasoolabad (672 mg/l) and Colonelganj (616 mg/l) (Fig. 7). The post monsoon data analysis reveals that the magnesium concentration is beyond permissible limit in Rishikul Mahavidyalay (137.1 mg/l) (Fig. 16). The iron concentration is beyond the permissible limit in Peepalgaon, Kareli, Khuldabad and Salori. The water quality index for pre-monsoon study showed that quality of water is poor in Salori,

Rasoolabadas well as nearby area of Rishikul Mahavidyalay and Peepalgaon (Fig. 18). The index also revealed that the Peepalgaon and Rishikul Mahavidyalay have very poor water quality (Fig. 18). The influences of solid waste dumping site, aquifer material mineralogy together with other anthropogenic activities and increased human interventions have adversely affected the groundwater quality in the study area. However, in post-monsoon water quality index map there is a shift of Peepalgaon from very poor quality to poor quality and status of Rishikul Mahavidyalay shifted from very poor to moderate class (Fig. 18). This improvement in WQI in these locations may be due to the dilution or recharge of fresh water.

The GIS based spatial and temporal variation using inverse distance weighting interpolation (IDW) in ArcGIS provides fair representation of temporal and spatial variation of various water quality parameters.

In the present study, 15 groundwater quality parameters viz. pH, TDS, EC, hardness, alkalinity, sulphate, chloride, nitrate, calcium, potassium, sodium, fluoride, iron, magnesium and bicarbonate were analyzed to assess the suitability of groundwater for drinking purpose in Allahabad City. Correlation matrix was also calculated and observed that pH is positively correlated with Na and Mg. TDS is positively correlated with F and sulphate is positively correlated with Mg. Na is positively correlated with Ca. Fluoride is positively correlated with potassium. Alkalinity is positively correlated with hardness, calcium and bicarbonate.

GIS has been applied to estimate the area falling under different water quality classes during the pre and post monsoon. Area having good water quality covers the area of 2.58 Km² also area comes under moderate, poor and very poor are 45.66 Km², 12.12 Km² and 0.66 Km² respectively during the pre-monsoon whereas during the post monsoon 24.61 Km² area comes under Good water quality. However, moderate and poor water quality areas reduced to 35.93 Km² and 0.47 Km² respectively.

Table 4 Classification of groundwater quality according to WQI range

WQI range	Type of water
0–55	Good
55–65	Moderate
65–70	Poor
70–75	Very poor
> 75	Not suitable for drinking

Conclusions

Groundwater is an important and reliable source for drinking purpose in Allahabad Smart city, it is necessary and important to know the groundwater quality at shallow depth (30–50mbgl). The study conducted for different groundwater quality parameters using GIS framework and WQI method has provided very significant outcome. The results pertaining to the groundwater quality obtained have been mapped using Arc-GIS (10.1). The areal coverage has also

been deciphered under different category of water quality in the city. It is concluded that in the study area during pre-monsoon, 4.23% area is falling under good, 74.82% under moderate and 12.12% under poor and 0.66% under very poor category. Analysis of water quality maps during post-monsoon period revealed that the 40.33% of area falls under good, 58.89% area under moderate and 0.77% under poor water quality. It is also concluded that groundwater depth has positive correlation with TDS. However, other groundwater quality parameters are not coherent with groundwater level.

The groundwater quality during pre- monsoon period reveals that it is more deteriorated than post-monsoon period. It may be due to rainfall recharge of groundwater. Therefore, the findings of the present research work may be a path finder or target the area and depth of the groundwater which may be suitable for drinking purpose.

Appendix

Tables 5 and 6.

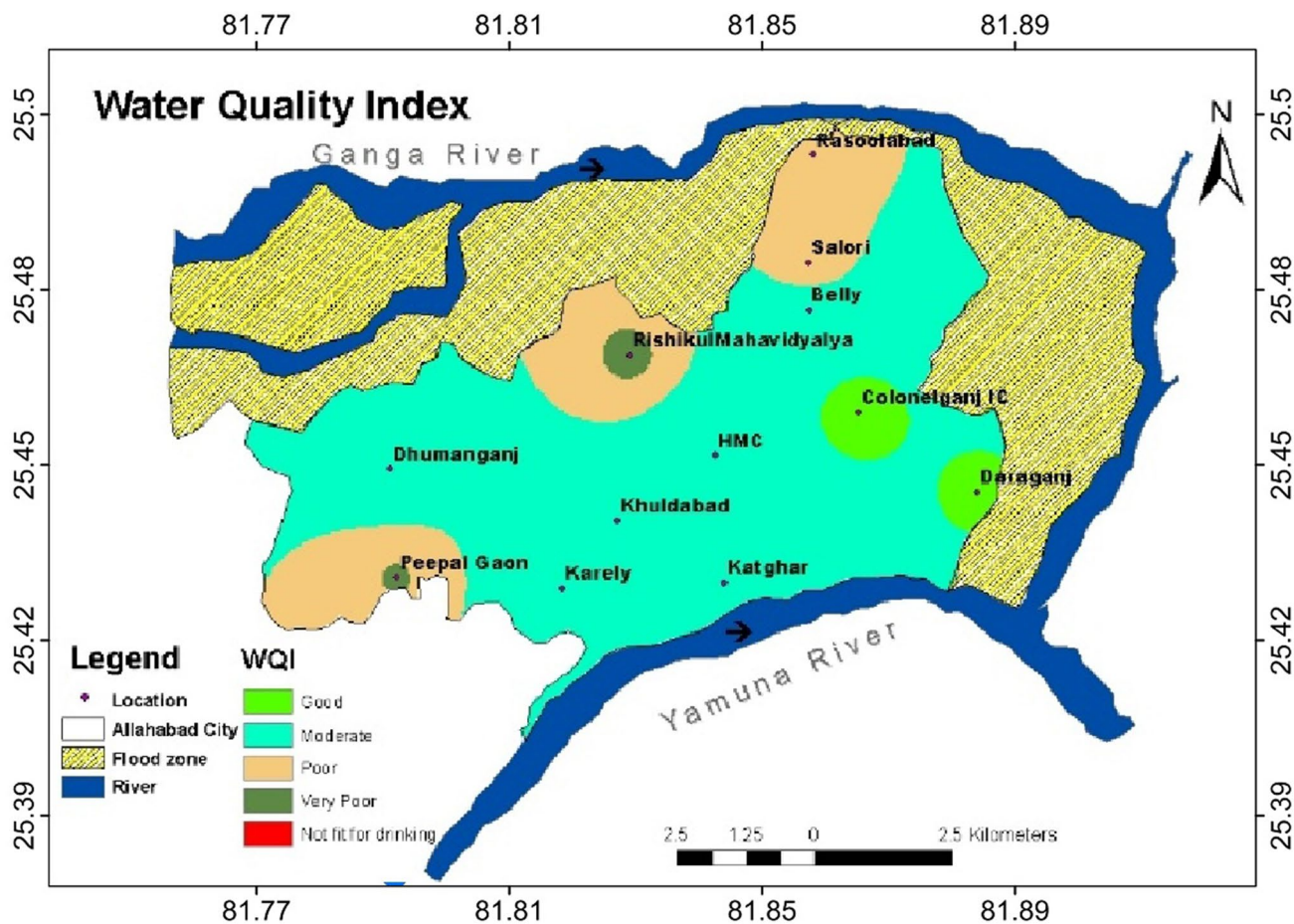


Fig. 18 Water quality index map during pre-monsoon

Table 5 Groundwater quality parameters during pre-monsoon (2018)

X	Y	Sample ID	Place	pH	Hardness	TDS	Alkalinity	Na	K	Calcium	Magnesium	Nitrate	Bicarbonate	Chloride	Sulphate	F	Fe	WQI
81.855183	25.499714	A1	Rasoolabad	7.84	512	689	672	85.4	4.74	176	99.1	9.3	512	161	81.6	0.89	0.61	67.35
81.785824	25.447908	A2	Dhumanganj	7.5	420	763	444	74.5	7.82	78	83.1	10.6	420	143	80.2	0.97	0.49	60.05
81.823071	25.439442	A3	Khuldabad	7.7	412	813	524	77.3	4.12	86	79.2	0.62	412	162	80.3	0.87	1.28	64.29
81.84055	25.429263	A4	Katghar	8	416	572	432	76.5	4.59	100	76.8	6.2	416	177	102.3	1.04	0.71	64.39
81.824997	25.466583	A5	RishikulMahav- idyalya	8	404	1109	436	76.5	4.59	100	149.7	6.2	404	131	302	1.04	0.71	71.28
81.882	25.4442	A6	Daraganj	7.7	440	572	432	75.5	3.69	84	86.5	3.2	440	143	119	0.71	0.54	53.95
81.814085	25.428305	A7	Karely	7.3	436	64	484	74.2	1.82	96	82.6	21.6	436	231	93.7	0.46	0.99	58.87
81.854539	25.474133	A8	Belly	7.6	336	781	468	69.9	3.69	76	111.8	11	336	149	155.8	0.94	0.54	60.09
81.854439	25.481862	A9	Salori	7.5	344	683	376	78.3	3.14	84	63.2	8.1	344	151	127.8	0.35	1.27	69.1
81.786904	25.430057	A10	PeepalGaon	7.4	320	1093	348	69.3	2.54	108	75.8	16.3	320	144	49.1	1.09	0.93	70.33
81.86266	25.457168	A11	Colonelganj IC	7.2	596	427	616	71.2	2.39	92	73.9	3.1	596	157	144	0.46	0.5	51.67
81.839027	25.450124	A12	HMC	7.8	488	540	524	74.4	3.81	124	88.5	9	488	118	135.6	0.59	0.54	57.15

Table 6 Groundwater quality parameters during post-monsoon (2017)

X	Y	Sample ID	Place	pH	EC	Hardness	TDS	Alkalinity	Na	K	Calcium	Magnesium	Nitrate	Bicarbonate	Chloride	Sulphate	F	Fe	WQI
81.855183	25.499714	A1	Rasoolabad	7.7	972.31	384	632	484	69	5	78	74	8.6	384	99	86	0.6	0.5	49.29
81.785824	25.447908	A2	Dhumanganj	7.4	1030.77	392	670	412	64	6.9	66	79	6.4	392	105	69	0.6	0.5	49.87
81.823071	25.439442	A3	Khuldabad	7.7	1046.15	372	680	512	74	3.6	72	73	0.1	372	95	65	0.8	1.7	63.74
81.84055	25.429263	A4	Katghar	7.5	638.46	372	415	392	70	3.1	88	69	8.1	392	137	68	0.9	0.7	55.20
81.824997	25.466583	A5	RishikulMa- havidyalya	7.8	1512.31	312	983	340	74	4.7	72	137	5.6	312	57	294	0.7	0.8	60.91
81.882	25.4442	A6	Daraganj	7.5	738.46	376	480	416	69	3.3	68	75	3.2	376	79	127	1	0.6	50.61
81.814085	25.428305	A7	Karely	7.2	892.31	412	580	444	64	1.8	64	85	19	412	113	92	0.2	1.3	56.04
81.854539	25.474133	A8	Belly	7.8	1033.85	268	672	356	78	3.5	60	99	9.4	268	65	180	1.1	0.6	57.83
81.854439	25.481862	A9	Salori	7.3	907.69	352	590	412	73	2.5	76	57	7.2	352	79	127	0.3	1.2	60.85
81.786904	25.430057	A10	PeepalGaon	7.6	1273.85	280	828	284	65	2.8	80	66	15	280	131	60	0.9	1.1	66.52
81.86266	25.457168	A11	Colonelganj IC	6.8	533.85	516	347	536	66	2.9	72	75	3.2	516	131	174	0.3	0.5	44.13
81.839027	25.450124	A12	HMC	7.7	736.92	384	479	412	71	3.4	96	70	8.8	384	108	140	0.4	0.7	53.66

References

- Alban K (2014) Simulink application on dynamic modeling of biological waste water treatment for aerator tank case. *Int J Sci Technol Res* 3(11):69–72
- Alban K, Irma K, Elisabeta P (2016) Simulink programming for dynamic modelling of activated sludge process: Aerator and settler tank case. *Fresenius Environ Bull* 25(8):2891–2899
- American Public Health Association (1995) *Standard Methods for the Examination of Water and Wastewater*, 19th edn. Byrd Prepress Springfield, Washington
- Anitha P, Charmaine J, Nagaraja S (2011) Evaluation of groundwater quality in and around Peenya industrial area of Bangalore, South India using GIS techniques. *Environ Monit Assess* 184(7):4067–4077
- Arumugam S (2010) Application of new bacterial regrowth potential method for water distribution system—a clear evidence of phosphorus limitation. *Water Res* 33(1):137–144
- BIS (2012) *Drinking water specification IS: 10500:2012*. Author, New Delhi
- A water quality index—crossing the psychological barrier. In: Jankis SH (ed) *Proc. Int. Conf. on Water Poll. Res.* Jerusalem, 6:787–797
- Dojlido JR, Raniszewski J, Woyciechowska J (1994) Water quality index applied to rivers in the Vistula river basin in Poland. *Environ Monit Assess* 33:33–42
- Environmental Systems Research Institute (ESRI) (1996) *ArcView Spatial Analyst. Advanced Spatial Analysis using Raster and Vector Data*, NY
- ICMR (1975) *Manual of standards of quality for drinking water supplies*. ICMR, New Delhi
- Kannel PR et al (2007) Application of water quality indices and dissolved oxygen as indicators of river water classification and urban impact assessment. *Environ Monit Assess* 132(2):93–110
- Kumar SK, Chandrasekar N, Seralathan P, Godson PS, Magesh NS (2011) Hydrogeochemical study of shallow carbonate aquifers, Rameswaram Island India. *Environ Monitor and Assess* 184(7):4127–4139
- Kumar SK, Kumaran AL, Magesh NS, Godson PS, Chandrasekar N (2014) Hydro geochemistry and application of water quality index (WQI) for groundwater quality assessment, Anna Nagar, part of Chennai City, Tamil Nadu. *Applied Water Science*, India
- Mangukiya R, Bhattacharya T, Chakraborty S (2012) Quality characterization of groundwater using water quality index in Surat city, Gujarat, India. *Int Res J Environ Sci* 1(4):4–23
- Mtetwa S, Schutte CF (2002) An interactive and participative approach to water quality management in agro-rural watersheds. *Water SA* 28(3):337–344
- Nasirian M (2007) A new water quality index for environmental contamination contributed by mineral processing: a case study of Amang (tin tailing) processing activity. *J Appl Sci* 7(20):2977–2987
- Pesce SF, Wunderlin DA (2000) Use of water quality indices to verify the impact of Cordoba city (Argentina) on Suquiariver. *Water Res* 34(11):2915–2936
- Raju N, Dey S, Das K (2009) Fluoride Contamination in Groundwaters of Sonbhadra District, Uttar Pradesh India. *Curr Sci* 96(7):979–985
- Ramakrishnaiah CR, Sadashivaiah C, Ranganna C (2009) Assessment of water quality index for the groundwater in Tumkur Taluk, Karnataka State India. *J Chem* 6(2):523–530
- Sadat-Noori SM, Ebrahimi K, Liaghat AM (2014) Groundwater quality assessment using the Water Quality Index and GIS in Saveh-Nobaran aquifer Iran. *Environ Earth Sci* 71(9):3827–3843
- Sargaonkar A, Deshpande V (2003) Development of an overall index of pollution for surface water based on general classification scheme in Indian context. *Environ Monit Assess* 89:43–67
- Singh P, Nath S, Prasad SC, Nema AK (2008) Selection of suitable aggregation function for estimation of aggregate pollution for river Ganges in India. *J Environ Eng* 134(8):689–701
- Singh S, Samaddar AB, Srivastava RK, Pandey HK (2014) Ground Water Recharge in Urban Areas – Experience of Rain Water Harvesting. *J Geol Soc India* 83:295–302
- Smith DG (1990) A better water quality indexing system for rivers and streams. *Water Res* 24(10):1237–1244
- Stambuk Giljanovic N (1999) Water quality evaluation by index in Dalmatia. *Water Res* 33(16):3423–3440
- WHO (1992) *International Standards for Drinking Water*. World Health Organization, Geneva

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.