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Statistical analysis and water quality index development using GIS of Mathura City, Uttar Pradesh, India

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ABSTRACT

Water quality index is the most effective tool used to portray the quality of a water reservoir to be used in versatile areas by human beings in one way or the other. The same can be represented through mathematical equations by converting various water quality parameters into a single number. Geographic information system (GIS) technique is an emerging tool where one can easily map the sampling areas and classify the domains in terms of spatial distribution parameters accordingly. A total number of 45 samples were collected from hand pumps and the bank of Yamuna river during the post-monsoon season in December 2016. The order of major dominance of cations in groundwater is Na > Mg > Ca > K and the anions is Cl > HCO_3 > SO_4 > NO_3 > F. In the present study, an attempt has been made to determine the WQI distribution by using GIS technique in Mathura city located in the state of Uttar Pradesh, India. To determine the cation and anion interactions in water samples of the study area, the Pearson correlation coefficient matrix has also been assessed. The obtained results indicate a strong correlation between TH and Cl with an *r*-value of 0. 949 at a significance level (*p*) of 0.0. However, the chloride ion exhibited a better relationship with TDS, Mg and Na with an *r*-value of 0.815, 0.922 and 0.769, respectively, and with a significance level (*p*) of 0.0. The iso-concentration distribution with the help of the inverse distance weight (IDW) method obtained from the results of various water quality index values of different locations has also been calculated. The lowest value of WQI which is 86 has been assessed in the sample from Sall location of the study area indicating the good water quality at the site. The highest value of 1,588 has been observed in the samples from the location Garhi Pisurti showing that the water quality is unsuitable for drinking purpose at the study area. It can be inferred that the water quality of North-West and North-East part of the study area is highly deteriorated and is not suitable for drinking purpose. The present study will help portray the water quality of the study area in terms of bathing, drinking and other commercial purposes as the study area are a sacred place for Hindu devotees. The obtained results will help improve the water quality of the study area by using some suitable techniques.

Keywords: Water quality index; GIS; Correlation coefficient; Spatial distribution

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1. Introduction

Day by day groundwater problems have increased drastically and the fresh water that is being used is at the verge of extinction and menace. Groundwater is an essential part and an imperative source of freshwater for millions of families that reside in villages and cities. The primary ability of existence and rehabilitation of groundwater has its significance in a dry and semi-dry region. Water can have some dissolved form of chemicals, which may create chronic health effect, change in taste and aesthetic issues. Both natural, as well as waste outflow with the poisonous mixes because of anthropogenic exercise cause serious issues to communities of the aquatic system and give a potential impact on human health [1]. The ion exchange of the groundwater of a specific region is extraordinary which might be altered chemically relying on a few factors, for example, soil–water interaction, the disintegration of mineral species and anthropogenic effects [2–5]. Facing deficiencies in quality water for drinking and agriculture processes, individuals begin scanning for appropriate groundwater stations. Breaking down the hydrochemistry of groundwater to evaluate the quality is essential for deciding its utilization for drinking and agricultural purposes [6]. According to the WHO, almost more than 70% of the diseases are mainly caused by water in human beings.

In the past few years, there is a growth in the mortality and morbidity rate due to the waterborne diseases in India. The rate of waterborne diseases is because of a falling apart open distribution system for drinking, expanding quantities of the contaminated private water system, and constrained to indirect waterborne infections. Some studies establish a relationship between groundwater contamination and its harmful effects on human and flora and fauna [7,8]. This demonstrates that altered water quality can add to water shortage as it confines its accessibility for both humans utility and for the biological system [9]. Qualitative and quantitative analyses of different types of water quality parameters can be used to assess the pollution status of water bodies. Contamination once went into the aquifer system stays for a long time, rendering its unsatisfactory quality for human utilization [10]. Land and water-based social activities have been causing pollution to the precious resources and its exploitation is causing aquifer contamination in certain instances. The significance of groundwater quality in the health of human beings recently attracted a great deal of interest [11].

Water quality indices (WQI) serve as a valuable pointer of water quality as proposed by Horton [12] and expresses the composite impact of various water quality parameters [13]. Although different equations are available to know the WQI, every one of them viably converts multiple physical and chemical parameters into a single value that indicates the water quality dimension, along these lines wiping out contrasts between the parameters utilized independently in the appraisal [14]. Subsequently, WQI of many rivers around the world, including Indian rivers, has been reported by various researchers. Kalavathy et al. [15] conducted a research on Cauvery river, Tamil Nadu, while Samantray et al. [16] conducted an investigation on Mahanadi and Atharabanki river, Paradip area. Also, Alam and Pathak [17] surveyed Ramganga river, U.P. while Joshi et al. [18], and Chauhan and Singh [19] carried out a study on Ganges river, Haridwar and Rishikesh, respectively. Various detailed investigations about water quality, trace metals in groundwater, major ion chemistry and the procedures controlling groundwater ion exchange has been completed in various regions in India [20–25]. Similar studies have also been carried out in the Ganga Plain [26–30]. WQI is the best tool used to impart data on the nature of a water repository for dividing groundwater quality for drinking purposes [31–35]. Statistical analysis in terms of correlation is highly effective to determine the common source of different ion and their dependence on each other. Ahmad and Khurshid [36] carried out a study of water quality in parts of the Hindon River basin, Ghaziabad and made statistical correlation of different ion and reveals that samples have shown a good positive correlation between Cl^-, Na^+, K^+ with EC, total dissolved solids (TDS) and Ca^{2+} with TH; Cl^- shows a positive association with Na^+ and K^+ in the post-monsoon season. Anomalously high values show studied samples can be ascribed to the higher contents of salts. Similarly, Charizopoulos et al. [37] conducted a study on assessment of natural and anthropogenic impacts in groundwater and reveal that the high correlation (>0.75) is seen between SO_4^{2-} with NO_3^- (0.78) and moderate relationship between Ca^{2+} with SO_4^{2-} (0.66) credited to the utilization of fertilizers. Furthermore, moderate correlation (0.65) between Na with SO_4^{2-} and Cl^- with SO_4^{2-} has been observed, associated with wastewater seepage.

The geographic information system (GIS) technique is a valuable tool that can be effectively used for mapping and classification of an area in terms of spatial distribution parameters. However, water quality investigations depend extensively on expository methods about ion estimation and for numerically displaying the concentrations of an ion in that particular region – the remote detecting technique couples it to make GIS models [38]. Considering the above-mentioned facts in view, a study was being planned with the objectives in order to determine the WQI of Mathura city in the state of Uttar Pradesh, India and its distribution patterns using GIS technique.

2. Materials and methods

2.1. Study area

Mathura is a city in the western region of Uttar Pradesh (Fig. 1). It is located approximately 50 km north of Agra. Mathura is believed to be the birthplace of Krishna, hence is a sacred place for believers of the Hindu faith. The population is about (2.5 billion) and lay as the biggest district in Uttar Pradesh, India. The examined area lies between longitudes 77° 17′ and 78° 12′ and latitude 27° 14′ and 27° 17′ and covers around 3,339 km^2. The study area falls in the toposheet no 54E and 54I of Survey of India. The regular monthly temperature keeps fluctuating between 36°C and 47°C in summer and 25°C and 32°C in winter with a yearly precipitation of 826 mm. The main drainage in the districts is the Yamuna river coming from Faridabad through Palwal and enters the territory from the north and after following a meandering course, passes out of the zone in the SSE direction into

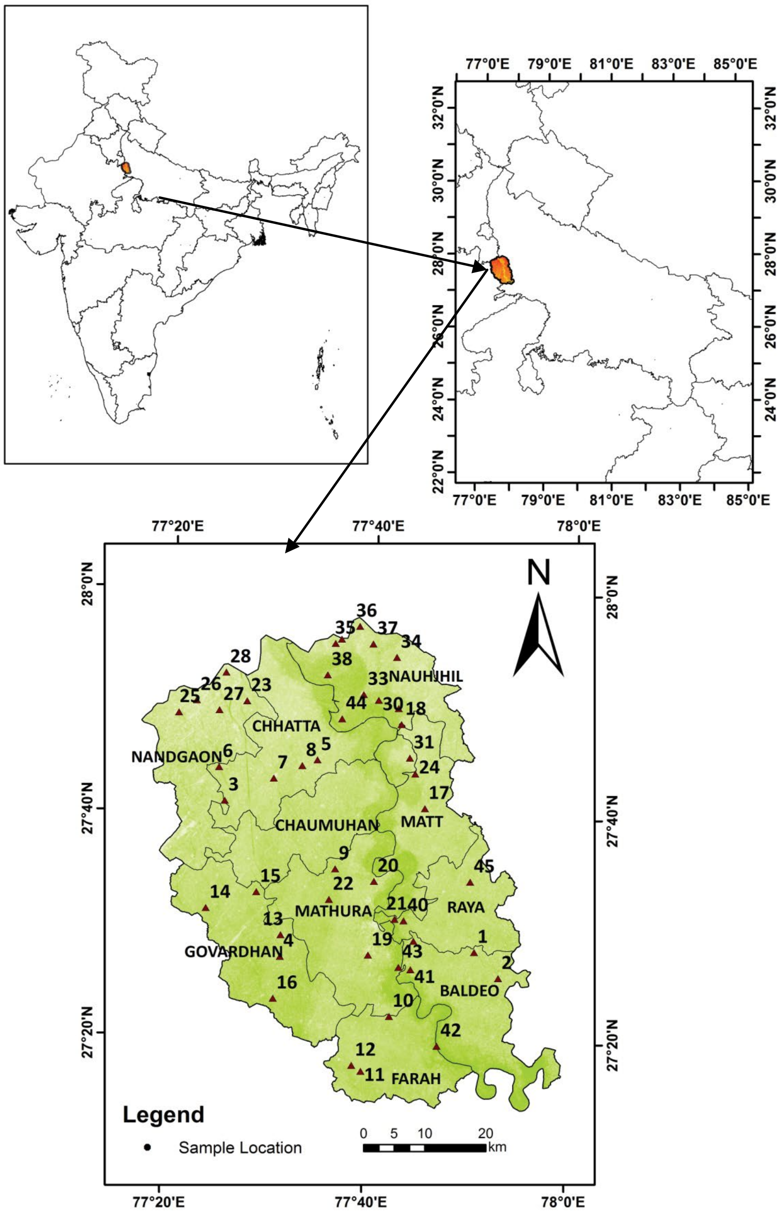

Fig. 1. Sample location map of the study region (Mathura district).

the Agra district. The soil type found in the study region is silty soil, sandy soil and loamy soil. According to the Central Ground Water Board, India, there are 61,456 tube-wells and 422 dug wells were reported in this region [39].

2.2. Geology of the study area

Study area shows the homogenous rock formation and does not demonstrate any symbolic structural complications. The rock formation has been tentatively lying in the Kaimur Formation and is delivered at a lower place: Quaternary alluvium consisting mainly of sands of various grade coarse-grained, quartzo-feldspathic sand, silt and sand with calcrete, clay, and kankar except for few NE-SW trending ridges (shown in Table 1). Alwar quartzite forms the strike ridge near Gobardhan. The quartzite strikes towards NE-SW and dip about 30° in the north-westerly direction. These quartzites are pre-eminently jointed in the bedding joint predominates. The other joints trend east-west N 75° E–S 75°W and are vertical [40]. Based on available Geological maps and records, the following stratigraphic sequence has been worked out.

2.3. Methodology

A range of polluted sources and water quality assessment in groundwater samples from the shallow aquifer were taken to find out the significant ions concentration in the study area. Site selection of samples is based on the potential area to pollution including agriculture, industrial and sewage discharges in the area. The coordinates of the sample locations in term of latitude and longitude were taken with the help of global positioning system. The GIS

Table 1
Geological succession of the study area [41]

Group	Age	Formation	Lithology
Quaternary	Holocene	Yamuna Recent Alluvium	Coarse-grained, quartzo-feldspathic sand reddish in color, occurs in patches in the western part and micaceous grey sand.
		Yamuna Terrace Alluvium	Composed of grey micaceous sand, clay and overbank silt.
		Mathura Older Alluvium	Composed of a multicyclic sequence of clay, silt and sand with calcrete.
	Middle to Late Pleistocene	Older Alluvium (Varanasi Alluvium)	Oxidized, Khaki to brownish yellow silt, clay with kankar disseminations, and grey to brown fine to medium grained sand.
Proterozoic-III	Vindhyan Supergroup		Upper Bhander sandstone, Quartzite, Phyllite and shale Group.

software version ArcGIS 10.4 has been used to prepare the integrated water quality index map and spatial maps for the different parameters as per the assessed concentration. The individual physicochemical parameters added in the raster calculator according to their relative importance in the overall quality of water.

In the present study, the quality of water samples was determined by the weighted arithmetic index. In this method, 11 parameters including TDS, calcium (Ca), magnesium (Mg), sodium (Na), potassium (K), sulfate (SO_4), chloride (Cl), bicarbonate (HCO_3), pH, fluoride (F) and nitrate (NO_3) has been undertaken for the assessment of WQI. A total number of 45 samples were collected from the bore penetrating in the shallow aquifer, during the post-monsoon season in December 2016. The water samples for the study were collected in 1-+L bottles pre-cleaned with HNO_3 polyethylene. And the samples were preserved and the concentration of all the parameters was determined as per the method prescribed by APHA [42].

The values of pH and electrical conductivity (EC) were being measured in the field with the help of the portable pH and EC meter. Volumetric titration method is being used to analyze calcium (Ca^{2+}), total hardness (TH), bicarbonate (HCO_3) and chloride (Cl^-) concentration. Sodium (Na^+) concentration has been detected by using Systronics flame photometer (UV-VIS) model (B/116-129, 1st floor, Supath-II Complex, Nr. Juna Wadaj Bus Terminus, Ashram Road, Ahmedabad-380013, Gujarat (India)). However, nitrate (NO_3^-) and sulfate (SO_4^{2-}) concentrations were analyzed with the help of UV-visible spectrophotometer (DR5000, HACH SALES & SERVICE LP, 3020 Gore Road, London, Ontario, N5V 4T7). The level of EC is expressed in μS/cm at 25°C whereas TDS, TH, Ca^{+2}, Mg^{+2}, Na^+, Cl^-, SO_4^{2-}, NO_3^-, HCO_3^{2-} and F^- are expressed in mg/L.

2.4. Water quality index

WQI was developed by Horton in the United States. It is the most useful tool used to calculate groundwater pollution and is very much efficient in the implementation of water quality upgrading program. The assigned weight reflected the significance of a particular parameter and has a considerable impact on the index which is based on (i) parameter selection, (ii) determination of quality function for each parameter, (iii) sub-indices aggregation with mathematical expression. In the present study, all the 11 parameters including pH, TDS, HCO_3, SO_4, Cl, F, NO_3, Ca, Na, K and Mg have been assigned a suitable weight as w_i as per its relative importance in affecting the overall quality of water [43]. The maximum weight value of 5 has been assigned to nitrate due to its significance in water quality assessment [44].

However, the weight value of 1 has been assigned to bicarbonate ions as it plays not much important role in water quality assessment. The other remaining parameters were assigned the weight value in between 1 and 5 (Table 2) and the relative weight (W_i) of each has been computed using the following equation:

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

where W_i is the relative weight, w_i is the weight of the parameter, n is the number of the parameters. After calculating the W_i values, the quantity rating scale in terms of q_i values for each variable has also been determined by dividing its concentration between each water samples and the result was multiplied by 100 as shown through Eq. (2).

$$q_i = \frac{C_i}{S_i} \times 100 \quad (2)$$

where q_i is the quantity rating, C_i is the concentration of chemical parameter of each sample (mg/L) and S_i is the drinking water standards for each chemical parameter (mg/L) as per the Indian standard (BIS:10500). Before computing the WQI values for each location, the SI values have also been determined for each parameter and then WQI has been determined using the following equations:

$$SI_i = W_i \times q_i \quad (3)$$

$$WQI = \sum SI_i \quad (4)$$

where SI_i is the sub-index of the ith parameter, q_i is the rating based on the concentration of the ith parameter and n is the number of parameters used in the present study.

Table 2
Details of chemical parameters and their relative weight and assigned weight with drinking standards as per [45,46]

S. No.	Parameters (mg/L) except pH	Indian standard (BIS 10500–1991)	WHO (2012)	Weight (w_i)	Relative weight (W_i)
1	TDS	500	500	5	0.1190
2	Bicarbonate	–	244	1	0.0238
3	Chloride	250	250	5	0.1190
4	Sulfate	200	200	5	0.1190
5	Nitrate	45	45	5	0.1190
6	Fluoride	1.0	1.5	5	0.1190
7	Calcium	75	200	3	0.0714
8	Magnesium	30	30	3	0.0714
9	Sodium	200	200	4	0.0952
10	Potassium	8	–	2	0.0476
11	pH	6.5–8.5	7.5	4	0.0952

The five types of classification of computed WQI values are shown in Table 3. Based on the ranking, the suitability and quality of water for human consumption and usage can be assessed.

3. Results and discussion

To evaluate the water quality parameters, the concentrations of the significant ions in all the water samples taken from different locations have been assessed and summarized in Table 4. Also, the water quality index for the same has been determined, the obtained values are depicted in Table 4.

3.1. pH

It is a critical part of elucidation process and sanitization of drinking water. For successful cleansing with chlorine, the pH value must ideally be below 8. However, the pH value of water <7 will probably be detrimental. Inability to limit erosion can bring about the tainting of drinking water and unfriendly impact on its taste and appearance. BIS has a prescribed allowable limit of pH to be in between 6.5 and 8.5. The pH estimation of groundwater tests in the present study lies in the range 6.8–8.3.

3.2. Electrical conductivity (EC)

Electrical conductivity, the measure of the concentration of a total ion in water is the important physio-chemical parameter determining the water quality. EC tells about the capacity of the water to convey electric discharge and higher EC shows enhancement of salts in the groundwater. The prescribed limit by WHO is 750 μS/cm. In the present study, the determined EC value in all the water samples ranges from 700 to 12,500 μS/cm with a mean value of 3,984 μS/cm. According to Sarath Prasanth et al. [47], EC in water can be classified into three types: type I (EC < 1,500 μS/cm); type II (EC: 1,500 and 3,000 μS/cm); and type III (EC > 3,000 μS/cm). Based on this classification of EC, 53% of the analyzed groundwater samples fall under type III (high enrichment of salts), 28% of the samples fall under type II (medium enrichment of salts) and 17% of the samples fall under type I (low enrichment of salts).

Table 3
Ranges of water quality index

S. No.	WQI ranges	Water quality
1	<50	Excellent
2	50–100	Good water
3	100–200	Poor water
4	200–300	Very poor water
5	>300	Water unsuitable for drinking purpose

3.3. Total dissolved solids

TDS, the centralization of aggregate inorganic salts and a little measure of natural salts disintegrated in the water is another vital physio-chemical parameters deciding the water quality. In the present study, the TDS concentration in all the groundwater samples has been observed to be in the range of 417–12,981 mg/L with a mean concentration level of 3,242 mg/L. However, the desirable limit of TDS in water for drinking as recommended by WHO and BIS is 500 mg/L. The concentration of TDS in all the 45 samples of the study area is found to be higher than the permissible limit prescribed by Indian Standard (BIS; IS 10500) indicating a severe concentration that can lead to ill health effects. Based on Todd [48] classification of TDS in terms of salinity, it can be inferred that about 73% of groundwater is brackish with TDS concentration in between 1,000 and 10,000 mg/L, about 20% is saline with TDS concentration in between 10,000 and 1,000,000 mg/L and less than 7% is fresh water with TDS concentration less than 1,000 mg/L.

3.4. Sodium, calcium, magnesium and potassium

Sodium, the imperative substance in water is having a permissible limit of 200 mg/L as per the limits prescribed by WHO standards. In the present study, the sodium

Table 4
Concentration of different water quality parameters in water samples of the study area

S. No.	Sampling locations	pH	TDS	K^+	Mg^{2+}	Na^+	Ca^{2+}	TH	HCO_3^{2-}	SO_4^{2-}	NO_3^-	F^-	Cl^-	WQI	Water quality type
1	Pachawar	7.4	799	55	109	170	11	476	533	103	17.7	0.21	298	129	Poor water
2	Dangheta	7.9	417	19	44	180	16	220	470	78	7.1	1.59	114	87	Good water
3	Khaeera	8.4	1,335	58	111	440	24	516	546	100	8.7	1.54	511	164	Poor water
4	Paigaon	7.8	1,122	6	21	420	35	172	832	111	9.6	1.27	256	113	Poor water
5	Janghawali	7.8	1,284	19	38	500	21	208	624	179	7.0	1.39	312	137	Poor water
6	Jab	7.2	10,121	200	331	840	1,459	5,000	325	623	18.5	0.89	4,402	892	Water unsuitable for drinking purpose
7	Ranbari	6.9	1,618	39	84	460	39	440	806	184	4.6	0.55	567	170	Poor water
8	Ladpur	7.6	1,306	22	126	390	18	560	780	147	9.1	0.73	327	147	Poor water
9	GLA University	7	1,633	19	275	70	109	1,400	384	184	3.8	0.03	583	770	Water unsuitable for drinking purpose
10	Barari	8.1	4,078	23	394	650	34	1,700	533	222	5.4	0.87	1,860	368	Water unsuitable for drinking purpose
11	Nagla Chitarsingh	7.9	1,170	13	335	220	50	1,500	677	240	5.3	0.44	566	196	Poor water
12	Sarurpur	7.3	5,717	31	317	780	281	2,000	546	4,17	9.1	0.82	2,016	441	Water unsuitable for drinking purpose
13	Ading	7	10,509	124	819	1,000	417	4,400	572	636	2.6	0.96	4,615	795	Water unsuitable for drinking purpose
14	Deoras	7.4	5,768	1,120	379	400	26	1,600	585	234	104	0.37	2,059	968	Water unsuitable for drinking purpose
15	Kunjera	7.7	833	18	370	220	32	1,600	620	177	10.7	1.25	384	195	Poor water
16	Lohariya patti	6.9	6,412	40	10	1,320	721	1,600	468	474	4.8	0.7	3,236	516	Water unsuitable for drinking purpose
17	Nasiti	7.4	886	11	398	180	27	1,700	772	362	4.9	0.55	532	205	Very poor water
18	Sultanpur	7.4	1,821	25	207	450	13	880	672	222	65	0.75	526	210	Very poor water
19	Narauli	6.9	1,631	11	280	210	21	1,200	620	102	35	1.03	540	192	Poor water
20	Vrindavan	7.7	2,285	13	109	520	21	500	650	116	32	1.16	625	190	Poor water
21	Laxminagar	8.1	1,502	6	49	400	16	240	689	78	2.7	1.71	426	134	Poor water
22	Bati	7.7	4,198	31	263	520	160	1,480	403	199	12.6	0.73	1,491	338	Water unsuitable for drinking purpose
23	Kharot	7.8	4,946	51	132	810	8	560	640	291	4.6	1.45	1,450	340	Water unsuitable for drinking purpose
24	Tainti gaon	7.2	6,869	31	362	810	39	1,580	146	583	20	1.44	2,356	490	Water unsuitable for drinking purpose
25	Kamar	7.7	6,534	40	950	1,420	1,192	6,700	494	709	0.4	1.07	8,363	1,054	Water unsuitable for drinking purpose
26	Dhaigaon	7.4	4,438	800	235	520	14	1,000	1,040	340	47	1.65	1,292	785	Water unsuitable for drinking purpose
27	Navipur	7.3	6,401	72	1,389	1,120	120	6,000	559	741	3.4	0.9	9,230	1,100	Water unsuitable for drinking purpose
28	Hetana	7.2	12,981	232	1,671	1,120	176	7,300	611	633	117	1.6	11,993	1,588	Water unsuitable for drinking purpose
29	Pithora	7.4	1,122	10	59	150	72	420	299	148	8.8	1.7	327	120	Poor water

30	Sall	8.2	423	14	31	130	29	200	351	60	21.2	1.65	170	86	Good water
31	Garhi pisurti	7.1	5,626	23	316	670	42	1,400	455	472	11.2	0.87	1,420	381	Water unsuitable for drinking purpose
32	Managadhi	6.9	2,405	22	24	270	321	900	390	218	4.2	0.89	852	195	Poor water
33	Naujheel market	6.8	4,615	670	151	320	281	1,320	949	286	191	0.67	1,050	730	Water unsuitable for drinking purpose
34	Edalgarhi	7.8	1,747	18	40	430	14	200	663	196	19.1	0.67	426	145	Poor water
35	Khajpur	7.4	4,359	31	224	650	225	1,480	546	238	4.4	1.3	1,775	358	Water unsuitable for drinking purpose
36	Matholi	7.3	2,475	22	136	480	98	800	559	137	28	0.72	951	221	Very poor water
37	Chandoli	7.6	728	8	110	220	19	500	572	102	14	1.25	256	113	Poor water
38	Masumna	7.8	1,095	13	141	190	24	640	325	287	102	0.71	355	161	Poor water
39	Karab	7.9	682	14	66	158	21	440	327	237	39.0	0.84	213	108	Poor water
40	Lohvan	7.4	2,371	14	210	430	16	900	780	228	34.2	0.63	866	225	Very poor water
41	Lalpur Mahavan	7.1	1,066	34	78	280	16	360	390	275	6.4	1.08	341	145	Poor water
42	Yamuna river	8.3	946	21	169	150	59	840	495	176	40	0.34	338	145	Poor water
43	Gokul barrage	7.2	712	31	22	190	67	260	416	161	30.4	0.3	185	99	Good water
44	Yamuna naujil	7.9	1,181	36	14	320	58	200	459	142	48.1	0.46	376	131	Poor water
45	Birhana	7.8	4,731	26	57	1,040	11	260	585	592	22	1.25	1,278	324	Water unsuitable for drinking purpose

concentration in the collected sample ranges from 70 to 1,420 mg/L with a mean value of 494 mg/L. It can be inferred that the sodium concentration of more than 83% of samples of the study area lies above the limits prescribed by WHO. The high values of sodium might be caused because of the deposition of salts from the silicate bearing minerals and artificial composts. However, the frequency of calcium ranges from 8 to 1,459 mg/L with a mean value of 144 mg/L. It can be inferred that the calcium concentration in less than 18% of all the collected samples is observed to be above the permissible limit of 200 mg/L as prescribed by WHO. Magnesium value is found to be very high in all the groundwater samples of the study area. The magnesium concentration of all the samples ranges from 975 to 1,671 mg/L with a mean of 259 mg/L. Results obtained in the present study indicates that most of the specimens are having magnesium concentration higher than the permissible limit of 30 mg/L as prescribed by WHO. Another essential parameter, potassium has also been determined. The level of potassium in all the samples lies from the range of 6–1,120 mg/L with a mean of 92 mg/L. The present study indicates that less than 73% of the samples of the study area contain potassium concentration higher than the permissible limit of 15 mg/L prescribed by WHO. Potassium exists in soils as a structural element of soil minerals, fixed between clay mineral lattice, adsorbed on exposed surfaces of minute soil particles and in the soil solution [49–51].

3.5. Total hardness (TH)

Total hardness is a valuable parameter in the assessment of water quality. It is calculated using the following equation [52]:

$$\text{TH}\left(\frac{\text{mg}}{\text{L}}\text{ as CaCO}_3\right)\text{Mg} = \text{Ca}^{2+} + \text{Mg}^{2+}\left(\frac{\text{meq}}{\text{l}}\right)\times 50 \quad (5)$$

The TH concentration in the present study lies in the range of 172–7,300 mg/L as $CaCO_3$ with a mean of 1,414 mg/L. From the present study, it can be observed that the TH concentration in 71% of the samples of the study area is higher than the prescribed limit of 500 mg/L laid by WHO thus indicating the collected water sample is unsuitable for drinking and household purposes.

3.6. Bicarbonate, sulfate, nitrate and chloride

The bicarbonate ions in terms of HCO_3^- have been determined in all the samples of the study area. The values of HCO_3^- in the present study lie in the rage of 146–1,040 mg/L, with a mean of 559 mg/L. In most of the samples, the level of HCO_3^- exceeds the maximum permissible limit of 200 mg/L prescribed by WHO. Bicarbonate ions occur in water because of the compound disintegration of carbonates and dissolution of CO_2. Sodium bicarbonate used to treat hyperkalemia. It works by increasing the movement of potassium from the blood into the cells. The sulfate ion concentration of all the samples of the study area has also been determined. The sulfate concentration of the collected specimens ranges from 60 to 741 mg/L. It can be observed that 48% of all the samples exceed the prescribed limit of 200 mg/L as laid by WHO. Anhydrites in the sedimentary rocks likewise contribute for sulfate particle. Levels of sulfate in rainwater and surface water correlate with emissions of sulfur dioxide from anthropogenic sources.

Nitrate is an important parameter required to be determined for the water to be used for drinking purpose. The concentration of nitrate has also been identified in all the samples collected in the present study. The observed nitrate concentration in all the samples lies in the range of 0.41–191 mg/L. Nitrate in groundwater mainly contributed from sewage waste and infiltration of agricultural runoff water from excessive use of the artificial fertilizers [53]. The high concentration of nitrate in drinking water causes methemoglobinemia known as a blue baby disease in infants. It happens due to nitrate metabolizing triglycerides present at higher frequencies than at other stages of development. The permissible limit for nitrate as per standards prescribed by WHO is 45 mg/L.

The concentration of chloride has also been determined in all the collected samples of the present study. The chloride concentration in the study area has been observed in the range of 114–11,993 mg/L with a mean of 1,602 mg/L. The maximum permissible limit given by WHO (2006) is 250 mg/L. Chloride salts are profoundly highly dissolvable and free from the synthetic response with the mineral of supply from the rock and stay in the type of sodium chloride. Large grouping of chloride ions shows a more elevated level of natural contamination.

3.7. Fluoride

Fluoride is an important parameter present in drinking water that is required by human beings for the growth of bones and other body parts. The fluoride concentration in all the samples has been determined in the present study. Result analysis carried out of all the collected samples of the study area indicates the fluoride concentration in the range of 0–1.71 mg/L with a mean level of 0.95 mg/L. However, the maximum permissible limit for fluoride as prescribed by WHO (2012) is 1.0 mg/L. Fluoride usually occurs in natural conditions; however, it is consumed by all human beings in a little amount [54]. Introduction in a living organism can happen through dietary admission, breath and fluoride supplements. The most critical factor for fluoride proximity in nourishment is fluoridated water. Danger can occur in the wake of ingesting at least one measurements of fluoride over a brief span, which at that point prompts harming.

3.8. Pearson correlation among ions

The close inspection of the correlation matrix is a useful tool required to point out associations between two or more variables that can show the overall coherence of the data set. It also indicates the participation of the individual chemical parameters in several influential factors, a fact which commonly occurs in hydrochemistry [55]. Samples showing r value greater than 0.7 are considered to be strongly correlated.

The Pearson correlation coefficient matrix has been determined in the present study, and data are summarized in Table 5. A perusal of the data summarized in Table 5 indicates that a strong correlation exists between TH and Cl with r-value of 0. 949 at a significant level (p) of 0.0. However, the chloride ion also exhibits a better correlation with TDS, Mg and Na with r-value of 0.815, 0.922 and 0.769, respectively, and with a significant level (p) of 0.0. Also, the parameter of TDS comprises of inorganic salts (principally calcium, magnesium, potassium, sodium, chlorides and sulfates) has shown a positive correlation with Mg, Na and SO_4 with r-value of 0.701, 0.801 and 0.828, respectively, with a significant level (p) of 0.0. These relationships imply that the major elements contribute to the salinity of groundwater and the tendencies among them follow a similar trend. This may result in salinization of groundwater from the effects of long-term interactions between groundwater and geological formations. The various correlations are shown in Table 5.

3.9. Spatial distribution characteristics

The iso-concentration distribution with the help of the inverse distance weight (IDW) method for various physio-chemical parameters analyzed in the present study has been calculated and is depicted in Figs. 2a–l. The distribution has been classified into five classes and portrayed with different colors regarding the increase in concentration. Orange and red colors indicate the areas with water not fit for drinking purpose. However, data through Fig. 2a show that the level of sodium is high in the NW part, SW part and some areas of the east side of the Mathura district. The rise in values may be due to the accumulation of salts that generally migrate from the near district of Rajasthan. The concentration of magnesium and potassium is found to be high in the NE part and Western part of the study area, as shown in Figs. 2b and c. It can be inferred that the concentration of the above-mentioned parameters in the study area is observed to be within the permissible limits prescribed by Indian Standard for water to be used for drinking purpose.

Perusal of the data through Fig. 2d indicates a vast distribution of the bicarbonates in the study area in all the sampling locations. The concentration of bicarbonates is higher than the permissible limits prescribed by WHO for drinking water in the NE part, West part and eastern part of the study area at different sampling locations. The fluoride concentration has also been determined and the distribution is portrayed through Fig. 2e. From Fig. 2e, it can be inferred that the study area near the state of Rajasthan and Agra city is having fluoride concentration higher than the permissible limits prescribed by WHO. It has also been observed that in nearly half of the study area the fluoride concentration is found to be more than 1 mg/L. The frequency of TH and chloride in terms of iso-concentration values has also been calculated and is shown through Figs. 2f and g, respectively. From Figs. 2f and g, it can be observed that the TH and chloride concentration values of the study area are found to be higher than the permissible limits prescribed by WHO for drinking water in proximity with the region of districts of Rajasthan state at NW part of the Agra district. The concentration of TDS is observed to be very high in the maximum number of specimens in the study area. However, the TDS concentration in very few samples of the study area is within the permissible limits prescribed by WHO. A perusal of the data from Fig. 2h it is observed that the Western part and the central part

Table 5
Correlation coefficient matrix of analyzed water quality parameter in all samples

	pH	TDS	K	Mg	Na	Ca	TH	HCO_3	SO_4	NO_3	Fl	Cl
pH	**1.00**											
TDS	**–0.39**	**1.00**										
	0.008*											
K	**–0.22**	**0.32**	**1.00**									
	0.147	0.031*										
Mg	**–0.21**	**0.70**	**0.14**	**1.00**								
	0.348	0.000*	0.176									
Na	**–0.20**	**0.81**	**0.04**	**0.57**	**1.00**							
	0.193	0.000*	0.775	0.000*								
Ca	**–0.26**	**0.56**	**0.05**	**0.27**	**0.56**	**1.00**						
	0.080	0.000*	0.721	0.073	0.000*							
TH	**–0.27**	**0.80**	**0.14**	**0.92**	**0.68**	**0.63**	**1.00**					
	0.070	0.000*	0.364	0.000*	0.000*	0.000*						
HCO_3	**–0.04**	**–0.06**	**0.36**	**0.02**	**0.00**	**–0.21**	**–0.07**	**1.00**				
	0.795	0.685	0.015*	0.876	0.998	0.156	0.642					
SO_4	**–0.35**	**0.83**	**0.12**	**0.70**	**0.82**	**0.56**	**0.80**	**–0.14**	**1.00**			
	0.017*	0.000*	0.422	0.000*	0.000*	0.000*	0.000*	0.375				
NO_3	**–0.18**	**0.19**	**0.61**	**0.15**	**–0.10**	**–0.07**	**0.09**	**0.23**	**0.04**	**1.00**		
	0.248	0.202	0.000*	0.332	0.522	0.651	0.540	0.128	0.816			
Fl	**0.27**	**0.14**	**–0.05**	**0.08**	**0.21**	**–0.05**	**0.04**	**0.01**	**0.05**	**–0.14**	**1.00**	
	0.069	0.354	0.766	0.605	0.159	0.746	0.773	0.947	0.743	0.367		
Cl	**–0.24**	**0.81**	**0.14**	**0.92**	**0.77**	**0.50**	**0.95**	**–0.06**	**0.79**	**0.13**	**0.15**	**1.00**
	0.114	0.000*	0.344	0.000*	0.000*	0.000*	0.000*	0.705	0.000*	0.392	0.332	

*Indicates that the correlation is significant ($p < 0.05$) and highly significant (<0.001).

of the study exceeds the permissible limit concentration of TDS as specified by WHO and BIS for drinking water. It has also been observed that the samples obtained from the western part of the study area, the TDS concentration surpasses more than 10,000 mg/L and can be seen through Fig. 2h.

The iso-concentration distribution data of all the samples of the study area about calcium and sulfate ions concentration is depicted through Figs. 2i and j, respectively. It can be observed that the calcium concentration is high in the west and northwest part of the study area, as shown in Fig. 2i. However, the sulfate concentration is observed to be maximum in the western, eastern and north-western part of the study area. From Fig. 2j, it can also be inferred that in the east of the study area the sulfate concentration is observed to be higher than the permissible limits prescribed by WHO for drinking water. The nitrate concentration of all the samples in terms of iso-concentration distribution data has been calculated and is shown through Fig. 2k. The value of nitrate is observed to be higher than the permissible limits prescribed by WHO in the western part and NE part of the study area. However, the pH values as depicted through Fig. 2l in all the samples except southern and western part of the study area is within the permissible limits prescribed by WHO for drinking water.

The iso-concentration distribution with the help of IDW method in terms of water quality index of all the analyzed samples of the study area has been evaluated and is shown through Fig. 3. The distribution has been classified into five classes and portrayed with different colors concerning the quality of water. Orange and red colors indicate the areas with water unsuitable and very poor for drinking purpose. However, the green and blue colors indicate good and excellent quality of water for drinking purpose, respectively. The water quality index values calculated from all the locations of the study area ranges from 86 to 1,588. The lowest WQI value of 86 has been assessed in the sample from Sall location of the study area indicating the good water quality of the city. The highest level of 1,588 has been observed in the samples from Garhi Pisurti location showing the water quality unsuitable for drinking purpose at the study area. A perusal of the data from Fig. 3 shows that the water quality of North-West and North-East part of the study area is highly deteriorated and is not suitable for drinking purpose. However, the water quality of the remaining part of the study area is observed to be of poor quality and not fit for drinking purpose. Therefore immediate remediation of the underground water is required and the control on groundwater contamination is immediately needed by enforcing some strict actions by the government agencies and organizations of the country.

The WQI map depicted (Fig. 3) furnishes more substantial insight into the water quality in the study area. The analysis of samples undertaken for study reveals that, a part of the only locality around Dangheta in SE part, consists of water suitable for drinking as well as irrigational purposes leaving rest of the areas with deteriorated water quality. The north-western, western and the south-western regions show

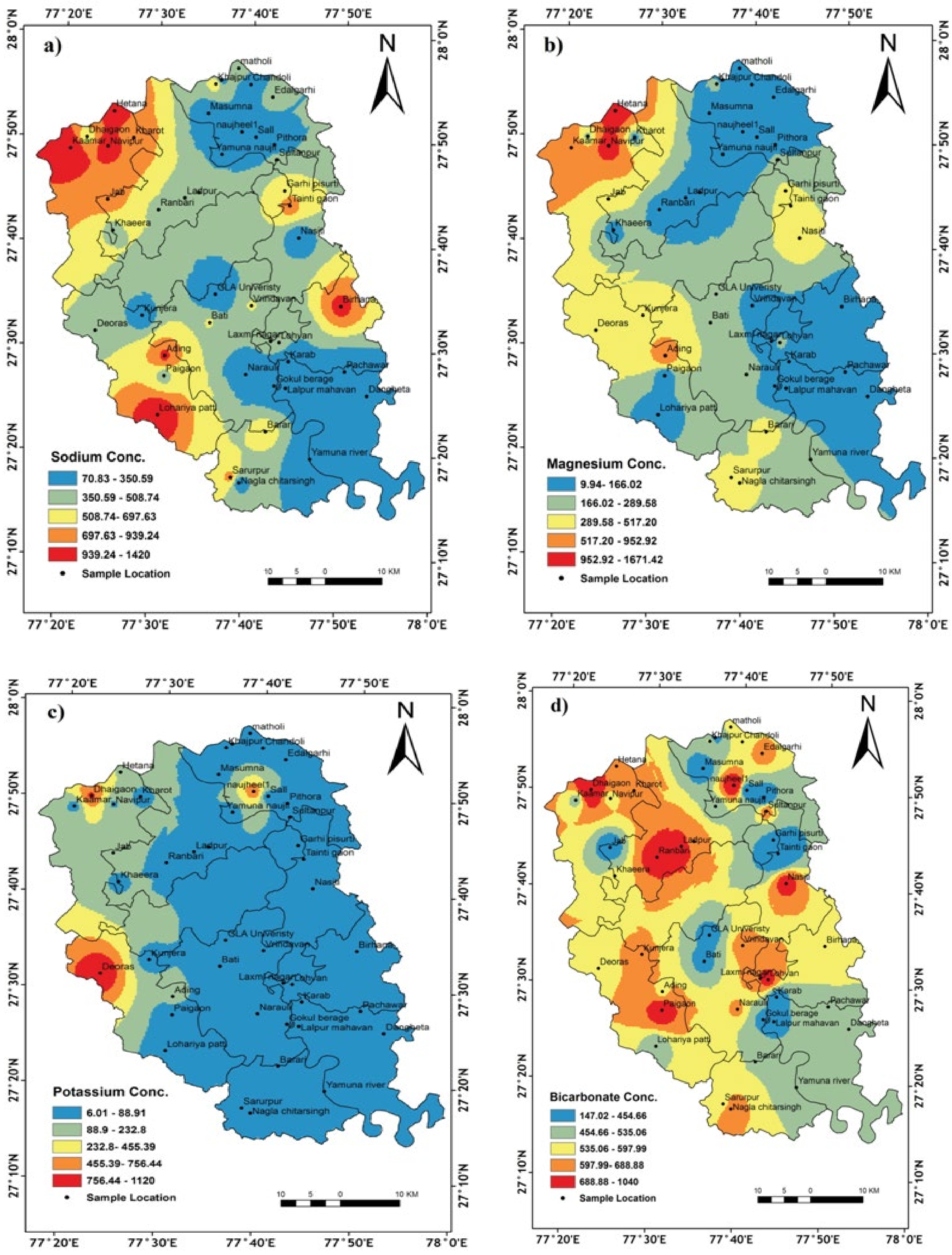

Figure 2 Continued

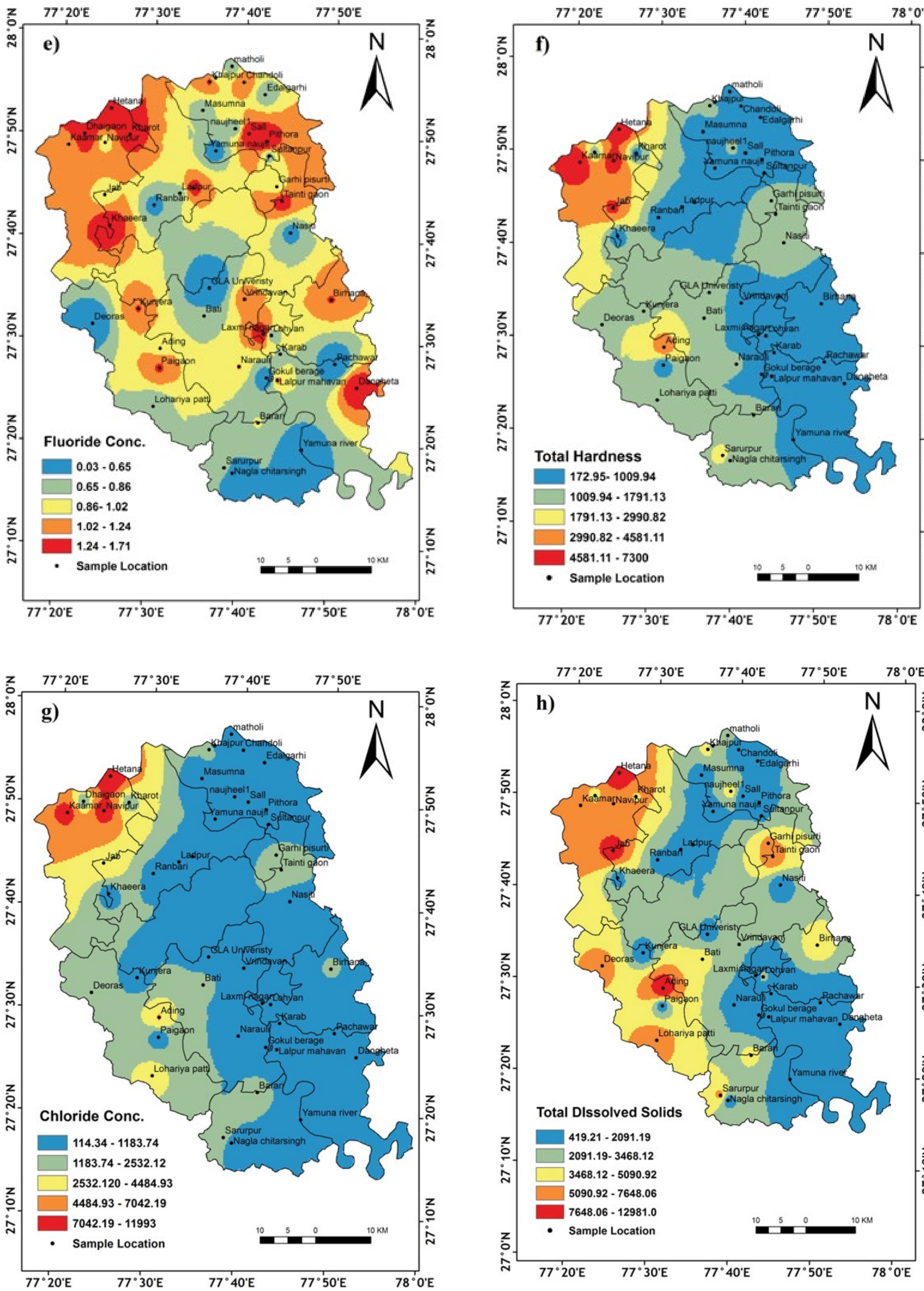

Figure 2 Continued

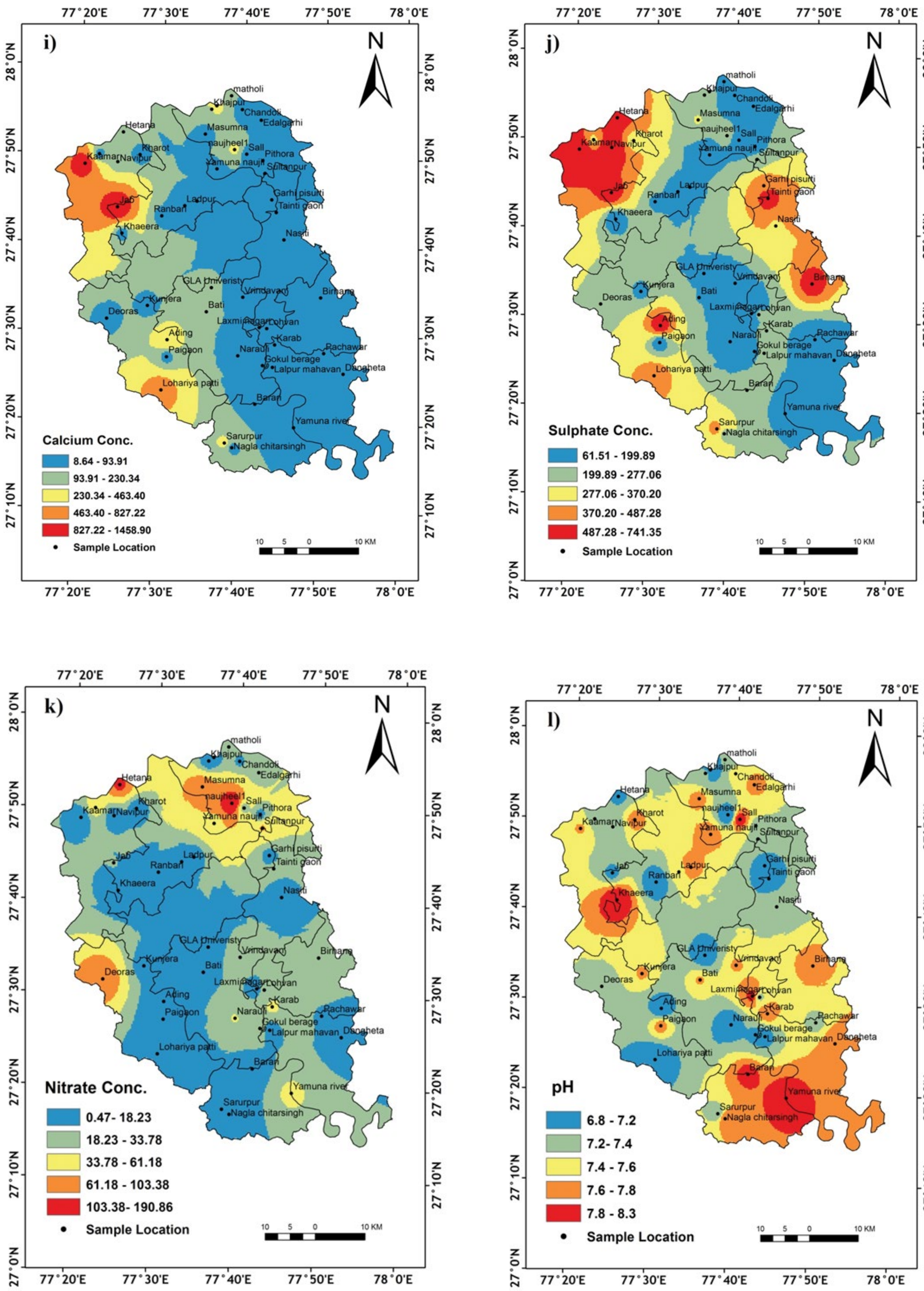

Fig. 2. Spatial distribution map of concentration of water quality parameter (a) sodium, (b) magnesium, (c) potassium, (d) bicarbonate, (e) fluoride, (f) total hardness, (g) chloride, (h) total dissolved solids, (i) calcium, (j) sulfate, (k) nitrate, and (l) pH.

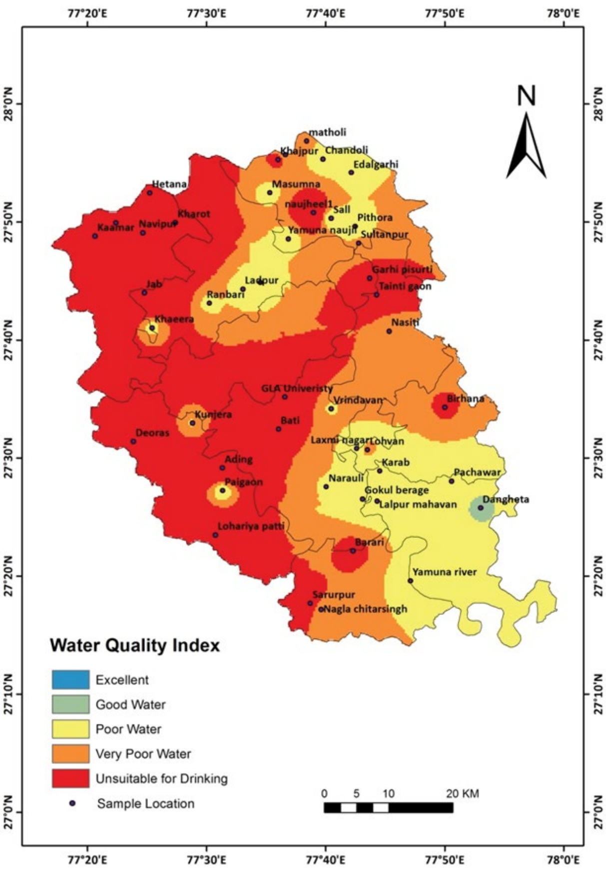

Fig. 3. GIS water quality index map of the study area.

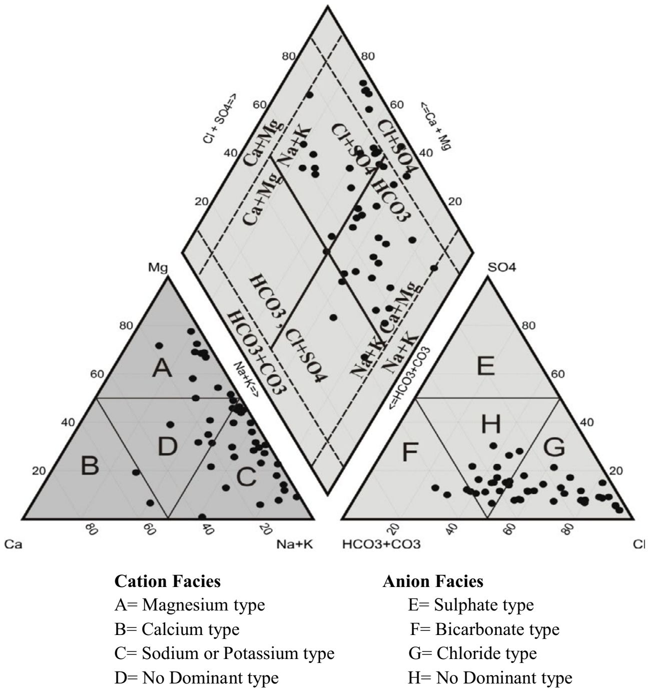

Fig. 4. Piper trilinear diagram showing different hydrochemical facies.

water quality unsuitable for drinking, due to higher TDS contents attributed to geo-genic sources. Poor water quality in and around the central part of the study area can be accredited to the anthropogenic activities. The study here brings to light that if no proper measures for the alleviation of water quality in the Mathura district are taken, ill-effects on the living population will be observed in due course of time.

3.10. Piper trilinear diagram

Piper plots, also known as Piper trilinear diagrams, are robust tools for visualizing the relative abundance of common ions present in ground-water [56]. The piper plots are explained using the facies classification of Back and Hanshaw [57]. It has extensively been used in groundwater hydrology to determine the suitability of water for human consumption. Differences and similarities within the groundwater samples can be identified from the trilinear plot because the water of similar qualities will occupy the same space as groups. For plotting the piper diagram, sample concentrations are normalized to 100 using the sum of cations equal to 100 and similarly sum of anions equal to 100 and all the calculations to be made on a percentage basis. The concentration of all the ions of all the samples of the study area has been used to plot the piper diagram and plots have been shown through Fig. 4. It can be inferred that the alkali concentrations are in abundance constituting 71% of cations, whereas 10% of the samples exhibit no principal character. While calcium concentration has been observed in 3% of samples, magnesium concentration is found to be dominant in 16% of the total samples. From Fig. 4, it can also be inferred that about 75% of the samples exhibits the chloride dominancy, while 21% of the total samples show no dominant character. However, 4% samples are found to be rich in sulfate among all anions. Data interpretation of diamond plots indicates that sodium chloride waters and calcium sulfate waters dominate the study region, followed by a small percentage of sodium bicarbonate waters.

4. Conclusion

Results obtained and assessed in the present study indicate that the water samples of the Mathura district are highly alkaline in nature. The ion dominance in the samples is Na^+ and Mg^+ in the cationic abundances and Cl^- and HCO_3^- in anionic abundances. Water chemistry of the study area strongly reflects the dominance of weathering of rock forming minerals with secondary contribution in anthropogenic sources. On the basis of statistical analysis of ion, a strong correlation has been found between TH and Cl with r-value of 0. 949 at a significant level (p) of 0.0. The chloride ion has also exhibited a better correlation with TDS, Mg and Na with r-value of 0.815, 0.922 and 0.769, respectively, with a significant level (p) of 0.0. It can also be inferred that about 75% of the samples exhibited the chloride dominancy, while 21% of the total samples show no dominant character. Data interpretation of diamond plots indicates that the water of the study region is dominated with sodium chloride and calcium sulfate followed by little concentration of sodium bicarbonate ions. The WQI values of all the locations ranges from 86 to 1,588. The lowest WQI value of 86 has been evaluated in the sample from Sall location of the study area indicating the good water quality. The highest WQI value of 1,588 has been observed in the samples from Garhi Pisurti location showing that the water quality is unsuitable for drinking purpose at the study area. From the determined WQI values of major part of the study region, it can be concluded that the drinking water possesses hazardous characteristics in term of human health. As the groundwater quality is seriously polluted, it is prescribed to the concerned authorities and organizations to complete quick remedial measures for the preservation of groundwater, implementing an immediate conservation plan.

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