Article

Hydrogeochemical characteristics, temporal and spatial variation for the evaluation of groundwater quality of Ganga alluvial plain for an agricultural region, India

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Abstract: Monitoring of groundwater quality in today's scenario is very much important. Due to urbanization and population pressure regular monitoring of groundwater for drinking as well as irrigation purposes need a major concern. With this aim, a study has been carried out consisting 26 groundwater samples in May 2017, to access the physiochemical characteristic, water quality index (WQI) of groundwater by using GIS software and to find out the groundwater suitableness for drinking as well as for irrigation purpose. The pH is slightly alkaline and the TDS is much more than prescribed limits of BIS. The trend of cations in groundwater are Ca^{2+}>Na^{+}>Mg^{2+}>K^{+} while anions trend is HCO_3^->SO_4^{2-}>Cl^->NO_3^->CO_3^{2-}>F^-. The Ca-Mg-HCO_3 and Na-K-Cl-SO_4 types of groundwater facies were dominant. Generally, the chemical changes in groundwater are administered by the evaporation process with ion exchange, and mixing of particles is the significant source of the solute acquisition process. WQI of the study area suggested that the 15% sample is unsuitable, 69% is poor and remaining is good for drinking uses. The potential salinity of the groundwater sample is nearly high although the majority of the sample is suited for irrigation activities.

Keywords: Groundwater quality; Shallow aquifers; agronomics; geospatial techniques; Aligarh

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1. Introduction

Groundwater is one of the most essential freshwater influencing indicators for the people around the world. Approximately 33% of the earth's community is assumed to utilize freshwater as drinking. Accessibility to hygienic freshwater is a basic requirement for social stability (Nickson et al., 2005). In many nations, however, the quality of drinking water, particularly in developed countries is low. In addition, subsurface water in arid and semi-arid areas is constrained by scarce precipitation, heavy evaporation and runoff in surfaces. (Suarez et al., 2015). The agriculture sector is a substantial user of groundwater. Groundwater quality may get disturbed if a change occurs in the mineral composition. This is usually caused by various activities like corrosion or incrustation of tube well screens, plant supplements, microscopic organisms, infections, pesticides, herbicides, hydrocarbons, trace metals and other dangerous synthetic compounds. Utilization of shallow subsurface as a transfer locales for the vast majority of the waste created for the city improvement viz. solid waste and wastewater has delivered disturbing, injurious consequences for the nature of the groundwater(Foster, 1998).The issues of groundwater quality are considerably more intense in the zones which are thickly populated, thickly industrialized and have shallow water level(V. T. Patil & Patil, 2010)**.**The tremendous improvement of urban regions resulting in overstressed localities and maltreatment of waste exchange practices has furthermore impacted groundwater quality. Based on the WHO report, most developing countries had dumped more than 65 % of its factories' outflow untreated into the water and made contamination surface and subsurface water supply (Ahmed et al.,2020 a,b; Ahmed et al., 2021; Christina Nunez, 2020).

The understanding of hydrochemistry is basic to be able to assess the groundwater vulnerability of any regions in which the groundwater is fundamental for both the domestic and agriculture process (Srinivas et al., 2013), and become very easy to understand when integrating with geospatial technology. The water quality assessment may give clear information about the subsurface geologic circumstances in which the water is present (Raju et al., 2011).

Aligarh is very close to the National Capital, Delhi and has quite fame as an education hub and a booming lock industry. This leads to tremendous growth and individuals moves for work and schooling and mainly all these contaminants settled very near to the old city, contributing to degradation and pollution of freshwater supplies. There is a limited supply for government water distribution systems, so the water demand of the Aligarh city is fulfilled by groundwater resources. Population pressure, industrialization, modern development plan leads to pollution of groundwater. So, it is important to investigate and evaluate the status of water pollution in the Aligarh district especially in and around the old city area. Many researcher highlighted the problems and concerns of of groundwater in Aligarh (Umar et al., 2000, Umar et al., 2006, 2007, 2012; Khan T, 2009; Haq S ,2013; Waseem et al., 2014; Khan et al.,2015; Priyadarshi et al., 2019, but no such study were carried out using geospatial technique for groundwater. Hence, the present investigation has been done to evaluate groundwater vulnerability using Geospatial application

2. Study Area Description, geology and hydrogeology

The field of research lies in between latitude 27^0 8′N and longitude 78^0 08′E with a population around 36.7 lakh and a land area of 4023 sq.km. Aligarh is situated in Uttar Pradesh Central Ganga Plain. Aligarh district is a plain tenderly slanting from North to South. Aligarh area is situated in a Shallow fluvial depression between the two noteworthy streams, the Ganga and Yamuna. The zone falls under a tropical monsoon sort of atmosphere where maximum rainfall occurs amid storm period (June-Sept.). Yearly rainfall measures around 708.7mm, and maximum temperature stays around 42^0C, amid May. In winter season temp ranges around 10^0C to 21^0C. The bedrock formation is experienced at a depth of 340 m below ground level (bgl). Alluvial sediments overlie Vindhyan formation in an unconformable way. The thickness of the rock bed ranges from 287 to 380 meters. Older alluvium possesses the upland of the region while the newer alluvium involves swamp region along with the courses of Ganga, Yamuna and their tributaries like Kali streams.((Sastri et al., 1971). Hydrogeological information demonstrates the territory is underlain by a thick pile of quaternary sediment that includes sand, different types of clay and kankar. The depth range of 00.00-122.00 meter bgl and constitutes the most potential aquifer group of the study area.

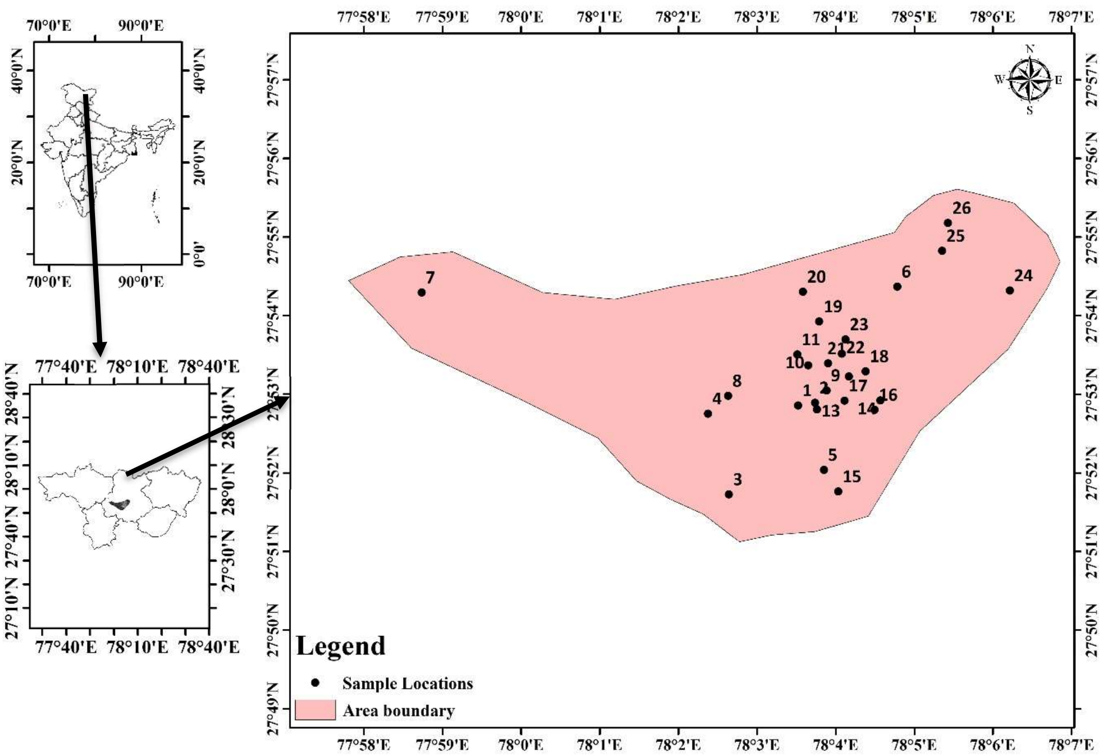

Figure 1. Study Area map with sample locations.

3. Methodology:

26 water samples were gathered from shallow aquifer of representative sites in various parts of the Aligarh district mainly from old city areas in May 2017 which is densely populated and thus is more prone to contamination of groundwater. Sample number 7 was taken from just outskirt area which was mainly open area while number 3 was

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taken from food processing factories area (Fig. 1). Physico-chemical investigation was conducted in May 2017 to be precise, in order to comprehend the chemical variations of the groundwater. Before taking samples, stagnant water from the aquifer had been removed by the initial withdrawal of water for 8– 10 minutes from the borehole Singh et al 2012). After removing stagnant water, the sample had been stored in polyethylene containers of one-liter at 4°C which was prewashed with 1N-HCl and double-distilled water. The samples were analyzed based on the standard techniques given by the American Public Health Association (APHA, 2005). EC and pH were estimated by pre-calibrated conductivity meter and portable pH meters in the field. TDS values were determined from EC by the conversion factor from 0.55 to 0.75 depending on the relative concentration of ions (Brown et al., 1970; Hem, 1991). Total hardness and Ca^{+2} were determined by EDTA titrimetric technique. Hardness is calculated by the difference of hardness of calcium and magnesium. Sulphate, nitrate and fluoride were analyzed from double beam UV–vis spectrophotometer. Chloride was determined by titration with AgNO3 solution, Na^{+}& K^{+} by Flame Emission Photometry and values of CO_3^{-} and HCO_3^{-} were also determined by titration. The variation of cations and anions concentration in the study area is plotted using ArcGIS 10.3 software.

4. Results and Discussion

The analytical results of the chemical investigation of groundwater are presented in Table.1 and their concentration range of major ions in groundwater compared with B.I.S. (2012) and W.H.O. (2011) drinking water standards (Table-2). The results showed that pH is slightly acidic to basic and varies from 6.70 to 9.50. The TDS varies from 313.40 to 2554 mg/l. The total hardness lies in the range of 59-188 mg/l in groundwater samples of the study region The order of cations are Na^{+} (21 to 336) > K^{+} (7 to 83) > Mg^{+2} (4.40 to 93.10) > Ca^{+2} (21.2 to 601.2) mg/l, while anionic order are HCO_3^{-} (351-1449) > SO_4^{-2} (79.10-732) > Cl^{-} (34.56- 502.70) >NO_3^{-} (2.44- 75.72) >F^{-} (0.04-1.89) mg/l.

Table 1. Physico-chemical parameters of groundwater samples in Aligarh city (all values in mg/l, except pH).

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S.no	Locations	latitude	longitude	pH	TDS	TH	Ca	Mg	Na	K	HCO3	CO3	SO4	NO3	Cl	F
1	Delhi gate	27.880968°	78.058705°	7.8	488.8	96	160.2	5.2	140	23	598	104	190.3	12.62	107.92	0.99
2	Kanwariganj	27.881523°	78.062314°	8.4	743.6	124	40	15.8	45	11	351	0	138.01	16.83	198.2	1.89
3	Talaspur	27.862138°	78.044048°	8.1	582.8	88	80.16	22	160	13	411	52	124.35	19.26	119.16	0.78
4	Shahjamal	27.879208°	78.039624°	8.8	797.6	128	46.5	11	248	28	403	0	517.84	2.66	184.6	0.31
5	Bhojpura	27.867332°	78.064183°	8.3	1563.2	124	46.8	5.2	303	53	351	0	731.72	42.30	502.68	0.38
6	Sarai Sultani	27.906178°	78.079750°	8.9	823.5	124	160.8	36.9	216	22	566	0	234.66	11.29	288.78	0.43
7	Khair Road	27.904926°	77.978915°	6.8	328.8	92	220.2	15.8	21	9	612	0	216.16	39.70	268.89	0.35
8	Gonda Road	27.883013°	78.043905°	7.4	765.4	104	186.8	7.9	159	18	673	0	79.09	18.15	266.33	0.81
9	Gudiya Bagh	27.884176°	78.064790°	6.7	1798.2	100	124.4	28.4	161	11	569	52	229.89	47.94	143.22	0.38
10	Ashok Nagar	27.889461°	78.060871°	8.7	966.7	220.8	170.7	29	139.3	38	718	0	282.3	13.95	118.23	0.43
11	Shaktinagar	27.891796°	78.058548°	9.5	2554	108	200.3	48.6	30	15	497	0	148.9	105.72	228.65	0.23
12	Rasalganj	27.887138°	78.069500°	8.9	1058.8	104	120.8	49.7	313	18	354	0	235.87	36.20	135.91	0.19
13	Upper Fort	27.880155°	78.062722°	8.2	943.7	319	87.2	44.2	335.6	38	987	0	123.58	7.44	338.98	1.44
14	Dubey ka padao	27.882025°	78.076160°	9.1	1314.5	324	160.2	34.4	166.4	83	873	52	167.67	44.65	186.69	0.08
15	Sasni gate	27.862771°	78.067221°	9.4	893.6	132	251.6	35.6	237	21	723	0	373.19	14.46	241.72	0.12
16	Madar gate	27.880051°	78.074916°	9.2	1078.9	124	120.24	19.3	215	19	531	0	445.56	37.42	331.44	0.19
17	Mahavi	27.8819	78.0685	8.4	1335	176	280.56	62.2	156	39	891	52	487.6	28.56	217.67	0.22

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	rganj	99°	58°													
18	Railway road	27.888190°	78.073014°	8.7	976	156	280.56	26.9	343	19	1281	0	354.23	24.56	142.33	0.26
19	Exibition Ground	27.898765°	78.063200°	8.1	950.6	112	200.4	54.3	251	17	1248	0	334.94	42.29	153.62	0.04
20	ITI road	27.905101°	78.059718°	8.3	376.8	92	240.48	38.9	38	7	728	78	258.77	19.70	66.48	0.13
21	Ramnagar colony	27.889903°	78.065077°	7.9	945	188	601.2	93.1	136.3	22	993	0	328.98	31.44	194.61	0.43
22	Sarai rahman	27.891972°	78.068004°	8	713	146	240.48	34.3	164	20	831	0	573.16	3.32	97.87	0.32
23	Nai basti	27.894992°	78.068759°	8.9	691	134	200.56	52.7	126	17	735	0	579.88	24.87	291.66	0.06
24	Quarsi	27.905327°	78.103607°	8.5	519.6	168	320.64	81.3	128	11	1103	0	579.69	9.67	68.98	0.09
25	SS nagar	27.913737°	78.089216°	8.6	313.4	81	160.32	39.4	67	28	673	0	533.92	14.61	34.56	1.89
26	Dhoerra	27.919665°	78.090484°	7.6	756.9	59	21.2	6.7	62	10	654	52	595.56	15.28	52.17	0.55

*The highlighted values are not within the permissible limit prescribed by BIS 2012.

0

Table 2. The concentration range of numerous major ions in groundwater samples for this investigation and their comparative analysis with B.I.S. (2012) and W.H.O. (2011) drinking water standards.

Water quality parameters.	BIS (2012)		WHO (2011)	Concentration in the study area	
	Highest desirable limit (mg/l)	Max. Permissible limit (mg/l)	Highest desirable limit (mg/l)	Min.	Max.
pH	6.5-8.5	No Relaxation	7.0-8.5	6.70	9.50
TDS	500	2000	500	313.40	2554.00
TH	200	600	500	59.00	324.00
Ca	75	200	75	21.20	601.20
Mg	30	100	30	5.20	93.10
Na	-	200	200	21.00	343.00
K	-	-	-	7.00	83.00
HCO_3	200	600	200	351.00	1281.00
SO_4	200	400	200	79.09	731.72
NO_3	45	No Relaxation	50	2.66	105.72
Cl	250	1000	250	34.56	502.68
F	1	1.5	0.6-1.5	0.04	1.89

4.1. Spatial variation of Physico-chemical Parameters

(i) Total Hardness (TH)

Hardness because of bicarbonate of calcium or magnesium is transitory hardness and permanent hardness is caused by the presence of nitrates of calcium and magnesium, sulphate and chloride. Soap consumption becomes more due to permanent hardness. It additionally delivers calcification of arteries. Stomach issues, poor health of kidney or bladder, urinary concretions are some of the symptoms delivered by hardness (Sengupta P. 2013). All the sample of the study area falls under the prescribe limits as set standard by BIS and WHO.

(ii) Total Dissolved Solids

Evaluation of total dissolved solids (TDS) is helpful to classify its suitability of water for farming, drinking and industrial activities. TDS is the total of carbonates, potassium, calcium, chlorides, sodium, bi-carbonates, phosphate, magnesium and different particles. If the concentration of TDS lies above the prescribed limit given by aforesaid standard, it causes a gastrointestinal problem in the human body. All the samples have TDS above 500 mg/l except 1,7,20 and 25 have values less than 500 mg/l.

(iii) Sodium

Sodium is a very reactive metal and therefore does not occur in its free form in nature. High sodium intake can have adverse effects on humans with high blood pressure or pregnant women suffering from toxemia. At room temperature, the average taste threshold for sodium is about 200 mg/l. Based on this, the sample 5,12,13 and 18 have exceptionally high concentration of sodium.

(iv) Calcium

Vascular contraction, blood clotting, nerve transmission and muscle contraction are mainly governed by the calcium. Taking an insignificant concentration of calcium is related with the risk of osteoporosis, colorectal cancer, kidney stone (Sorensen MD.2014). A high concentration of calcium in drinking should be avoided if suffering

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from kidney stones or bladder stones. The calcium values in 21 and 24 samples are intolerable.

(v) Potassium

Potassium is a fundamental component in a human body. Unfriendly health impacts because of potassium utilization in daily life from drinking water are probably not going to happen in peoples.

(vi) Magnesium

Deficiency of magnesium is an important cause for the different health risks to humans such as atherosclerotic vascular disease, eclampsia in pregnant women, vasoconstrictions, acute myocardial infection and hypertension (Geiger, H., & Wanner, C. 2012). The value in the sample 17,19,21 and 24 showing extremely high value of magnesium in the study area.

(vii) Alkalinity

Alkalinity is the water depends on bicarbonates, carbonates and hydroxides. BIS has prescribed limit 200 mg/l as acceptable and 600 mg/l as permissible for total alkalinity as $CaCO_3$. Bicarbonate ions are the main source of alkalinity in groundwater. Some of the areas are showing extremely high value of bicarbonate like samples 13, 14,15,18,19 and 24.

(viii) Sulphate

Polluted water probably has a high concentration of sulfate. Salts, acid derivatives, and peroxides of sulfate are widely used in the industry. Gastrointestinal irritations are noticed due to excessive concentration of sulfate in water. The sample numbers 4, 5, 24, 25 and 26 in the study area showing value more than the permissible limits as prescribe by the BIS.

(ix) Chloride

Chlorides are naturally occurred in water because of sewage disposal, leaching of chloride-containing rocks, ice-cream plant effluent, irrigation drainage and effluents from chemical industries. The higher concentration of chloride is injurious to the heart and kidney. Palatability, indigestion, taste, and corrosion are also enhanced effects of chloride. Sample 5,13 and 16 have high value of chloride concentration.

(x) Nitrate

Nitrate reaches in groundwater due to the leaching of nitrate with the percolating water to the soil. Its concentration more than 45 mg/l causes cyanosis in infants (Young et al., 1976) and it additionally influences the cardiovascular and sensory system and creates gastric cancer in adults(Yang et al., 1998). In shakti nagar area the value (105.72 mg/l) of nitrate is exceptionally high.

(xi) Fluoride

Fluoride is a geogenic contaminant. Fluoride in little amount for a long time impacts the dental problems. Higher values of fluoride cause skeletal and dental fluorosis (Ayoob, S., & Gupta, A. K. 2006; WHO,

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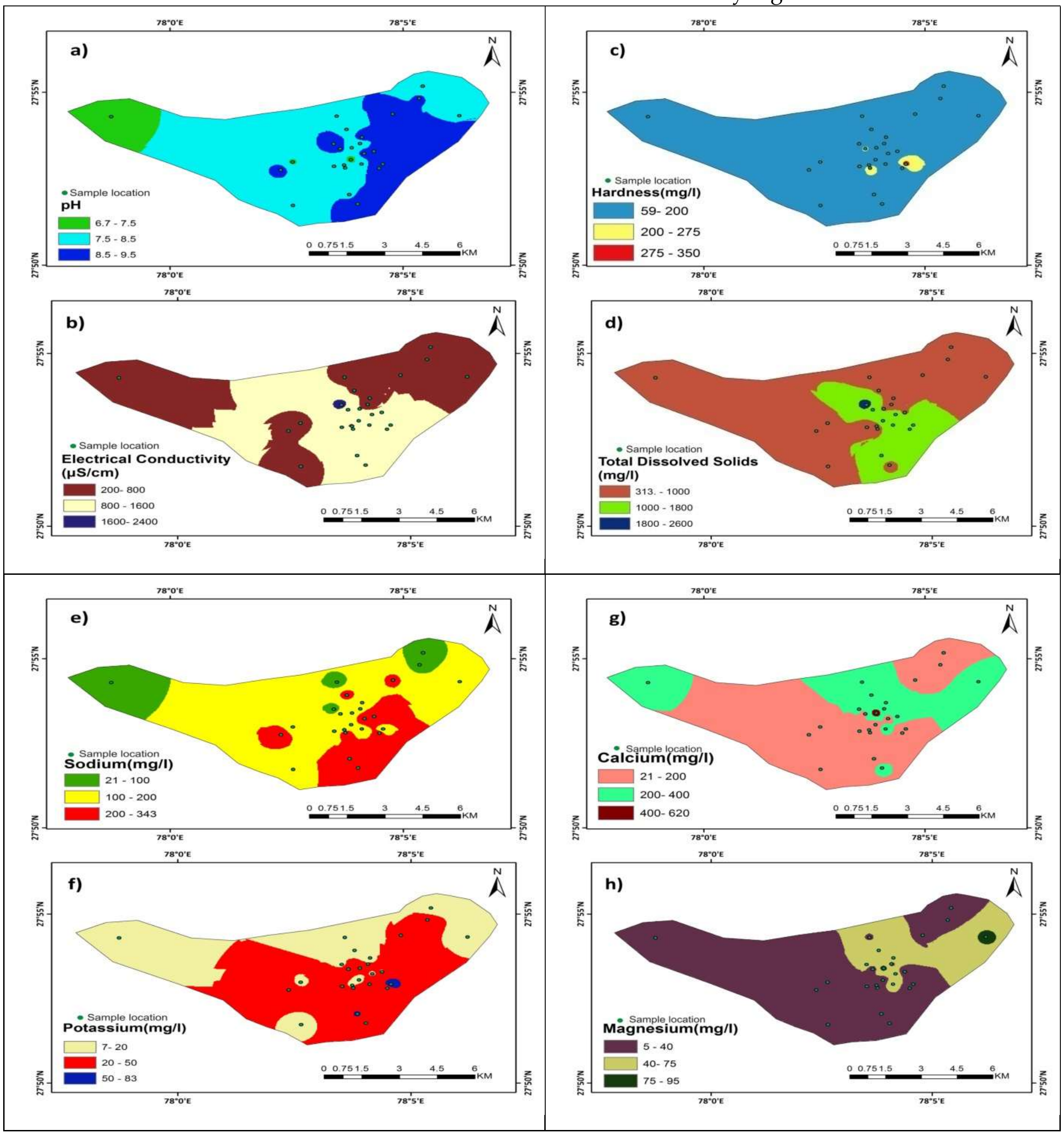
2012,). The fluoride values in groundwater samples lie from 0.04-1.89 mg/l. However the sample 25 shows the value above 1.50 mg/l.

Figure (2 a-m) were prepared using inverse distance weight (IDW) interpolation in a GIS environment to show the spatial distribution for various physio-chemical parameters. The map shows variation in the concentration of different ions in the study region.



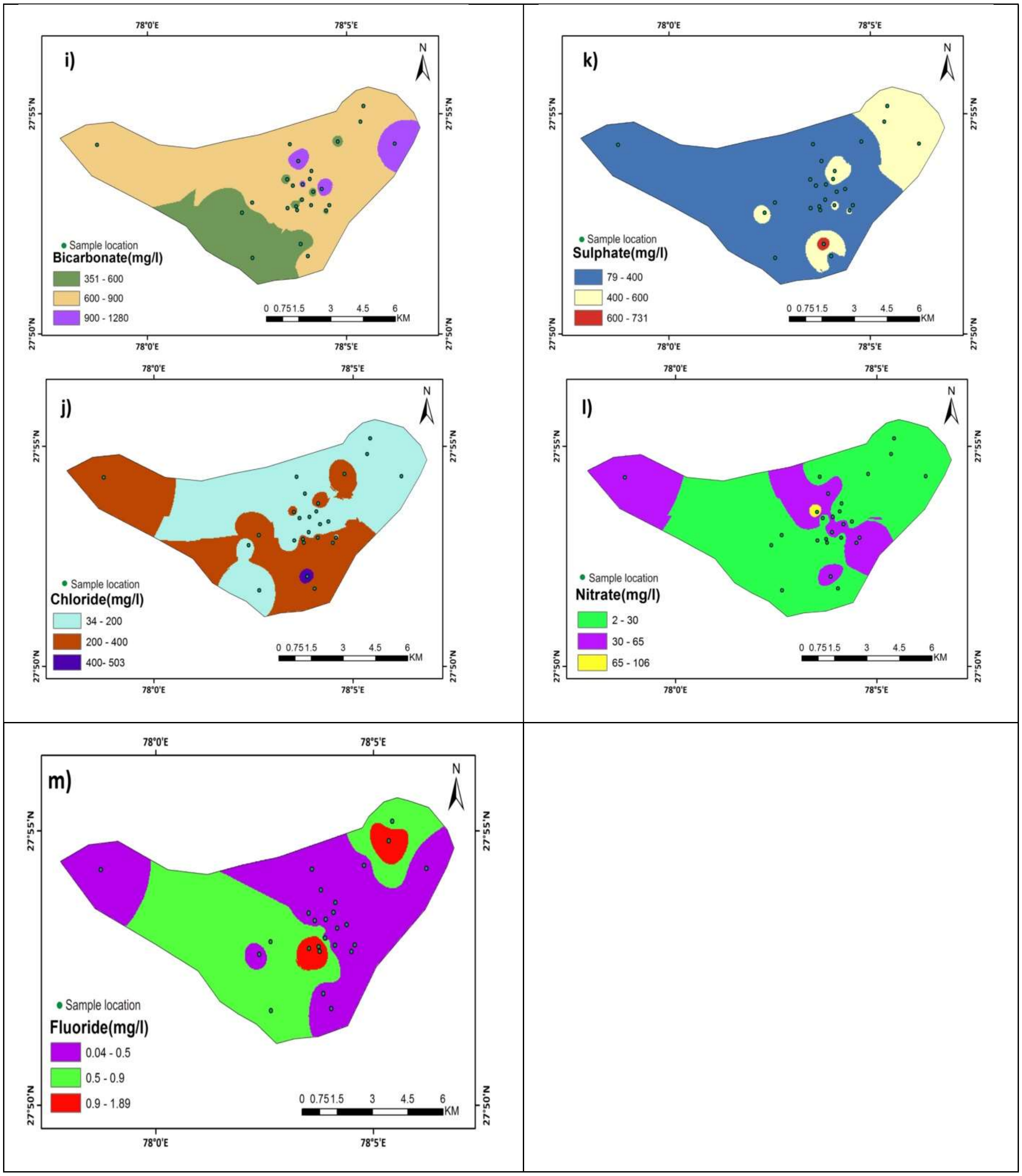


Figure 2. a-m):-Spatial distribution of different ion concentrations in the study area.

4.2:. Hydro-geochemical facies

Characterization of hydrogeochemical information can be done by knowing the hydrochemical facies of water. To understand about the facies, different plots like Durov (Durov, 1948) chart, Piper (Piper, 1944) trilinear diagram are used. Piper diagram is useful to figure out the chemical relationship in more definite terms (Walton, 1970).

In the present study, Piper plots have been plotted by utilizing the software Aquachem 9.0 to demonstrate the trend of major ions in every water sample.

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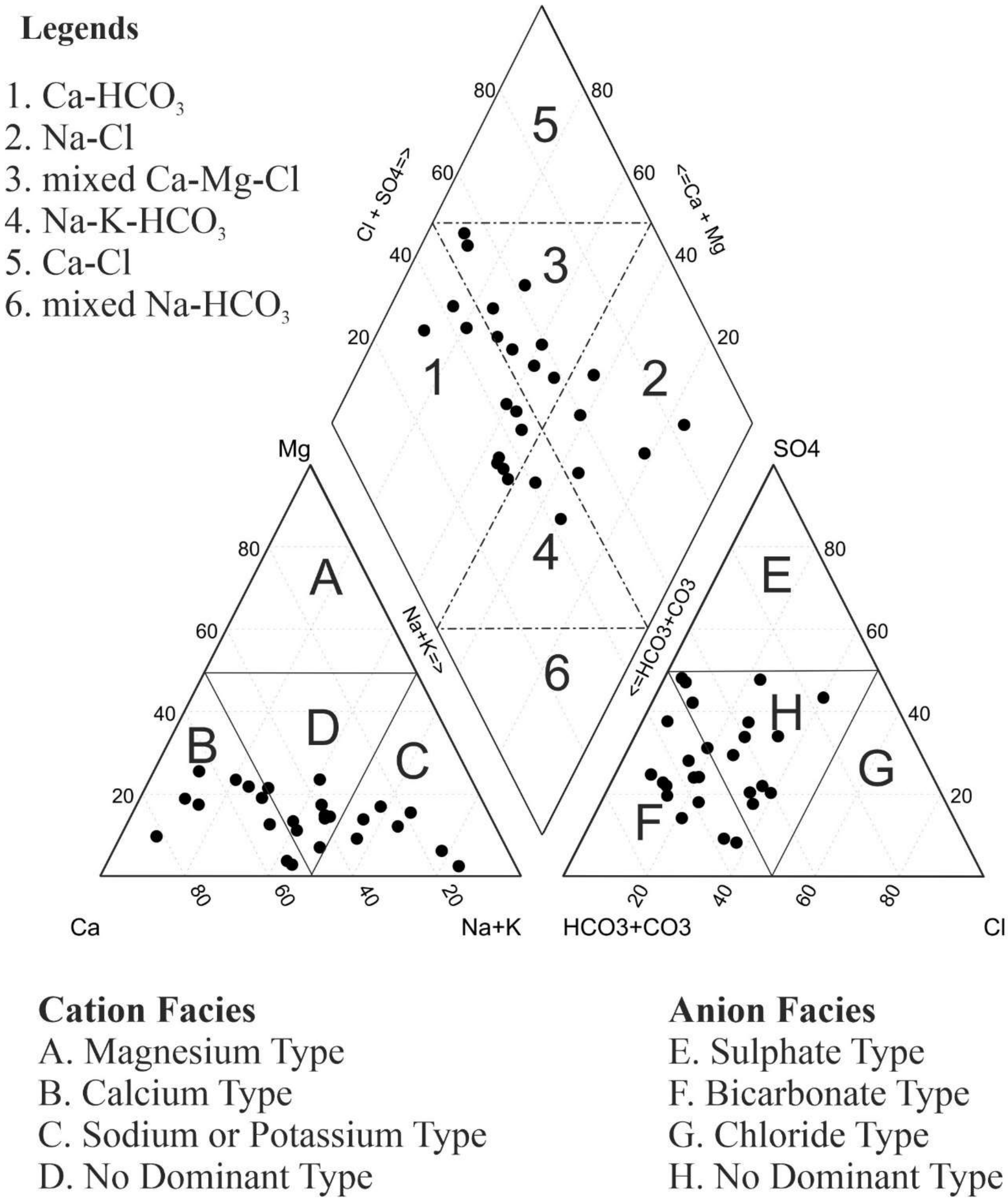

Figure 3. Piper Trilinear Diagram which showing different hydrochemical facies.

From the piper diagram (Fig 3) the central diamond field, both cations and anions were projected to identify the types of facies and it was found that Ca-Mg-HCO_3 and Na-K-Cl-SO_4 types of facies were dominating while mixed Ca-Mg-Cl and and Na-K-HCO_3 types also found.

4.3:. Source of solute in groundwater:

The source of solute in groundwater can be determined by using Gibbs ratio and Indices of Base Exchange (*IBE*)

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a) **Gibbs ratio:** The investigation on the sources of dissolved minerals content in groundwater can be conducted by using the Gibbs (Gibbs, 1970) diagram. It is of two types

Gibbs ratio I for Anion= $\frac{Cl^-}{Cl^- + H\quad^-}$

Gibbs ratio II for Cation= $\frac{Na^+ + K^+}{Na^+ + K^+ + Ca^{2+}}$

In **Fig 4**. the TDS values are plotted versus Gibbs ratio I and Gibbs ratio II furnish remarkable data that can help determine natural elements that affect the groundwater chemistry. These factors include evaporation processes, dissolution of rocks, and meteoric precipitations. The Gibbs's ratio I and II values of the study area 0.08 to 0.71 with an average of 0.32 and 0.09 to 0.96 of 0.48 respectively (Table 10) and water samples from Aligarh shows that the chemistry is governed dominantly by evaporation process as discussed in **Fig 4.**

b) **IBE:** The ion exchange between the water and its host condition comprehended by examining the chloro-alkaline indices. To understand the direction of exchange during the path of groundwater through the aquifer, Schoeller (Schoeller, 1965, 1977) proposed two chloro-alkaline indices CaI1 and CaI2 to demonstrate the exchange of ions among groundwater and its host condition.

$CAI\ 1 = Cl^- - (Na^+ + K^+)/Cl^-$

$CAI\ 2 = Cl^- [(Na^+ + K^+)/SO_4^{2-}] + HCO_3^- + CO_3^{2-} + NO_3^-$

If the value is negative, there is an exchange of Mg^{2+} and Ca^{2+} of the water with Na^+ and K^+ of the rocks and if positive there is an exchange of Na^+ and K^+ from the water with Mg^{2+} and Ca^{2+} of the rocks. In the study area, the value of CAI 1 varies from -2.75 to 13.15 with a mean value of 3.62 and CAI 2 ranges from 7.35 to 23.84 with mean of 16.45 which signify that both CAI 1and CAI 2 are positive and indicates that there is an exchange of Na^+ and K^+ ions from the water with Mg^{2+} and Ca^{2+} of the soil/rocks in maximum water samples but in some sample CAI 1 is negative which reveal exchange of $Mg^{2+}$and Ca^{2+} of the water with Na^+ and K^+ of the rocks (**Table 10**). It has been also found that the exchange and mixing of ions in the study area is deciphered by Durov's plot (**Fig 5**).

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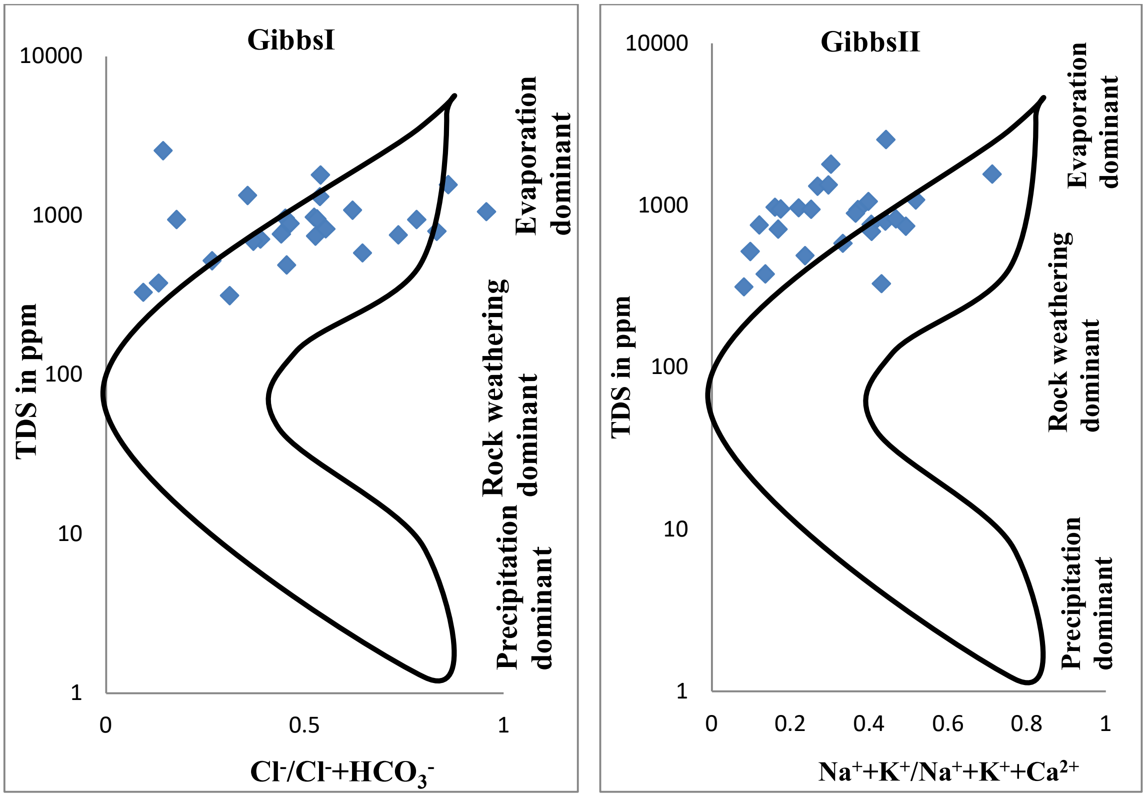

Figure 4. Gibbs's diagram for the water samples.

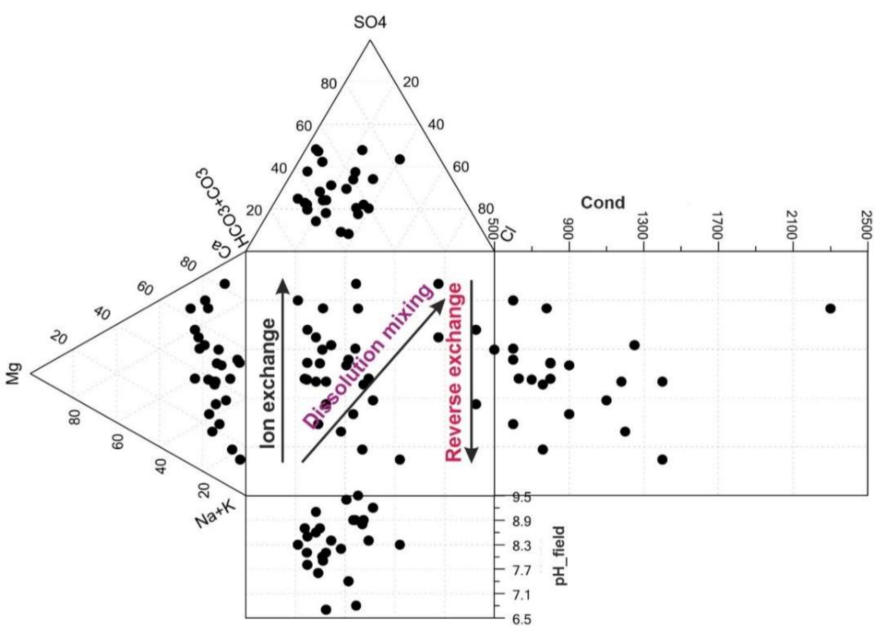

Figure 5: Durov's diagram for the groundwater samples

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The scatter plot (**Fig 6.a**) of Ca^{2+} vs. Na^{+} shows that most of the sample is below equiline indicates that ion exchange process which increases the calcium ions in the groundwater. However, few samples have excess of sodium ions, which indicates an anthropogenic source. The ratio (**Table 10**) of Na^{+}/Cl^{-} varies from 0.12 to 3.72 with mean value of 1.64; about 73% of the sample having the value of Na^{+}/Cl^{-} >1 which indicates no halite's source and release of Na ions from saline soil, weathering or might be an anthropogenic source and also remaining sample have Na^{+}/Cl^{-} <1 suggesting that ion exchange process (**Fig 6.b**).

The ratio (**Fig 6.c**) of HCO_3^{-} / Tz^{+} >1 is 93% of the sample and scatter plot between HCO_3^{-} vs. Tz^{+} fall above 1:1 line which signifies that influence of anthropogenic sources acting in the study as a secondary source after evaporation process which acts as a primary source of ions in the groundwater. The plot (**Fig 6.d**) of Ca^{2+} +Mg^{2+} vs. HCO_3^{-}+SO_4^{2-} shows that most of the sample is over HCO_3^{-}+SO_4^{2-} ions than Ca^{2+} +Mg^{2+} signify ions exchange process while sample below 1:1 line indicates reverse ion exchange process.

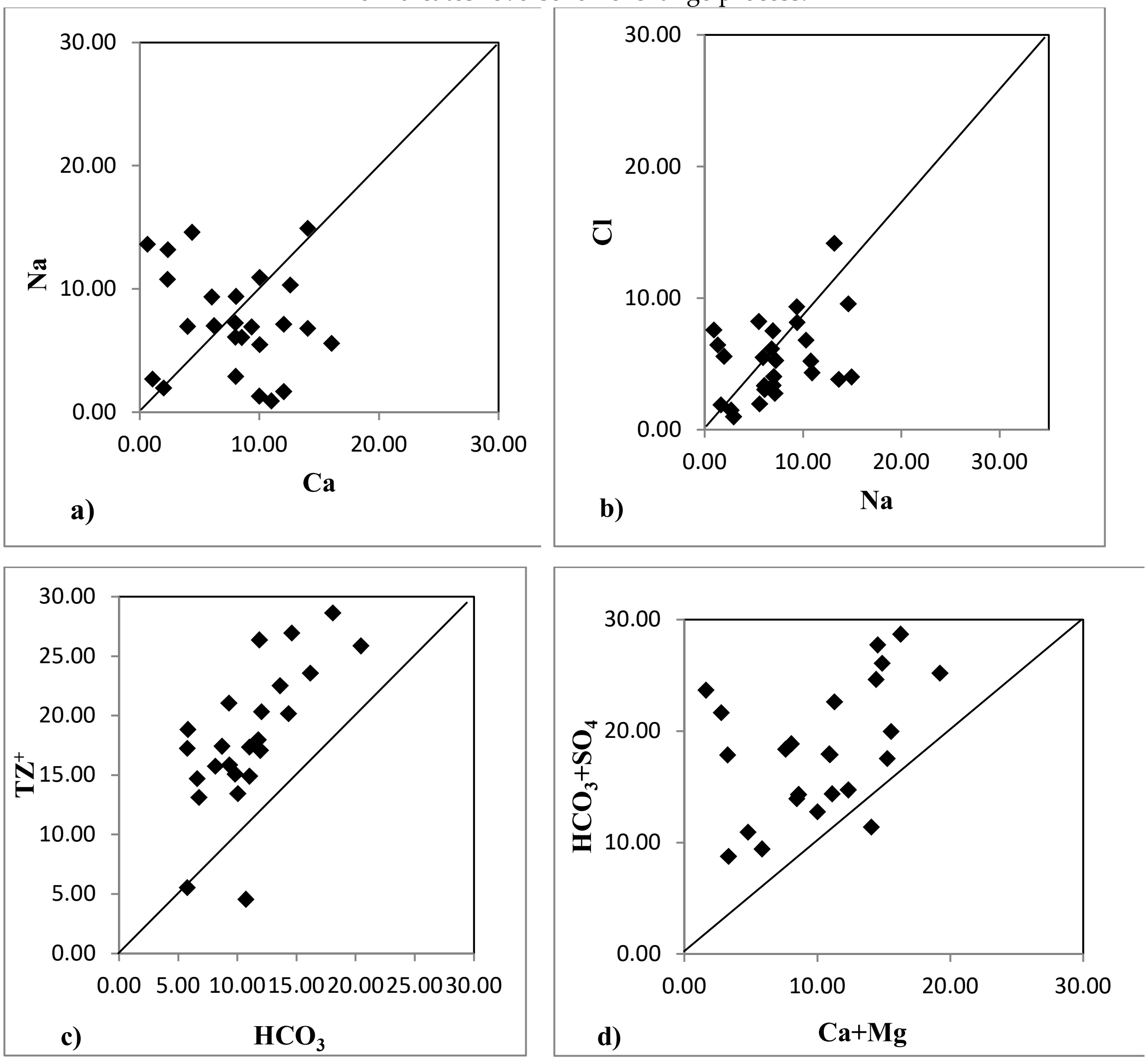

Figure 6. Scatter plot (a) Ca^{2+} vs. Na^{+} (b) Na^{+} vs. Cl^{-} (c) HCO_3^{-} vs. Tz^{+} (d) Ca^{2+} +Mg^{2+} vs. HCO_3^{-}+SO_4^{2-} (units of ions in meq/l).

4.4:. Water quality index (WQI) Estimation

Water Quality Index (WQI) is viewed as one of the best approaches to determine the surface as well as groundwater pollution and can be used efficiently in the implementation of water quality upgrading programs. It is based on mathematical equations and is used to change vast amounts of water quality information into a single number which represents the water quality. In various nation-wide investigations, the water quality of various water assets has been evaluated based on different water quality indices. In the study, the WQI has been determined in three stages. In the initial step, every one of the 11 parameters (pH, TDS, HCO_3, Cl, SO_4, NO_3, F, Ca, Mg, Na and K) has been assigned a weight (w_i) as per its relative significance in the overall quality of water for domestic purposes (Table 3). The rating scales were fixed regarding perfect estimations of various physicochemical parameters based on their importance. Even if, different ions are present, they might not be the ruling factor. Hence, they were assigned zero values. For ascertaining WQI, the following four equations were used.

The WQI model is given by equation 1:

$$\mathbf{WQI} = \frac{\sum_{i=1}^{n} \mathrm{W_i Q_i}}{\sum_{i=1}^{n} \mathrm{W_i}} \qquad \mathbf{(1)}$$

The quality rating scale (Qi) for each parameter is assigned, given in equation 2:

$$Q_i = 100[(X_i\text{-}Y_0/S_i\text{-}Y_0)] \qquad \mathbf{(2)}$$

The unit weight (W_i) is calculated as equation 3.

$$W_i = K/S_i \qquad \mathbf{(3)}$$

Where K is proportionality constant as described in equation

$$K=\frac{1}{\sum_{i=1}^{n}\frac{1}{Si}} \qquad \mathbf{(4)}$$

where Qi is the quality rating,, W_i is the unit weight of the i^{th} parameter, n is the number of parameters, X_i is the monitored value of the parameter, Y_o is the ideal parameter and S_i is the standard value of the i^{th} parameter.

Table 3. Chemical parameters and their relative weight and assigned weight compared with the drinking standards as per WHO (2011) & BIS (2012).

S. No.	*Parameters (mg/L) except pH*	*BIS (2012)*	*WHO (2011)*	*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	Sulphate	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	

Table 4. Water Quality Index range used in India for drinking water.

S. No.	*Range*	*Quality*
1.	0-25	Excellent
2.	26-50	Good
3.	51-75	Poor
4.	76-100	Very poor
5.	Above 100	Unsuitable for drinking

Based on the calculation the WQI of the study area was calculated and found that maximum samples exhibit poor quality in the study area (**Table 4**). The spatial distribution map of the Water Quality Index (**Fig 7**) was prepared to classify and make a well explanation of water quality in the study region. The pink, light yellow, light blue and purple color is used to describe the index i.e. Good, Poor Very poor, and Unsuitable for drinking respectively. The patches of pink colour found in the western part and some minor patches near to the northern part are showing good quality water because these are open area, an open area has good water quality than the closed areas due to infiltration, less runoff and have a higher microbial activity that captures contaminants(Cunningham et al., 2010). Light yellow colour patch shows the poor quality of the region which covers the eastern part, some small patches found in central and in the western part. The patch covered the central part and moved towards the northwestern part and the second patch covers the north-eastern part denoted by light blue color covered the most of the study area. These areas were highly affected and have very poor quality. The water lying in the category of unsuitable for drinking is denoted by the purple colour. Small areas in the central region and a major patch in the northern are classified and thus make a warning for bad water quality. So overall the WQI of the study area suggested that 15% sample is unsuitable, 69% is poor and remaining is good for drinking purposes. The poor quality of drinking water due lock, food processing industry and illegal factories running in the houses in the varsity of old Aligarh city create major problems of groundwater quality.

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Table 5. Water Quality Index of the study area.

S.No	*Locations*	*GWQI*	*Quality of Groundwater*
1	Delhi gate	101.7	Unsuitable to drink
2	Kanwariganj	190.3	Unsuitable to drink
3	Talaspur	91.94	Very poor
4	Shahjamal	70.73	Poor
5	Bhojpura	66.96	Poor
6	Sarai Sultani	84.82	Very poor
7	Khair Road	27.09	Good
8	Gonda Road	78.23	Very poor
9	Gudiya Bagh	30.27	Good
10	Ashok Nagar	78.55	Very poor
11	Shaktinagar	86.11	Very poor
12	Rasalganj	67.1	Poor
13	Upper Fort	149.7	Unsuitable to drink
14	Dubey ka padao	59.61	Poor
15	Sasni gate	69.1	Poor
16	Madar gate	72.43	Poor
17	Mahaviranj	59.75	Poor
18	Railway road	66.41	Poor
19	Exibition Ground	37.11	Good
20	ITI road	46.41	Good
21	Ramnagar colony	67.58	Poor
22	Sarai rahman	55.03	Poor
23	Nai basti	56.17	Poor
24	Quarsi	52.04	Poor
25	S.S Nagar	195.5	Unsuitable to drink
26	Dhoerra	61.94	Poor

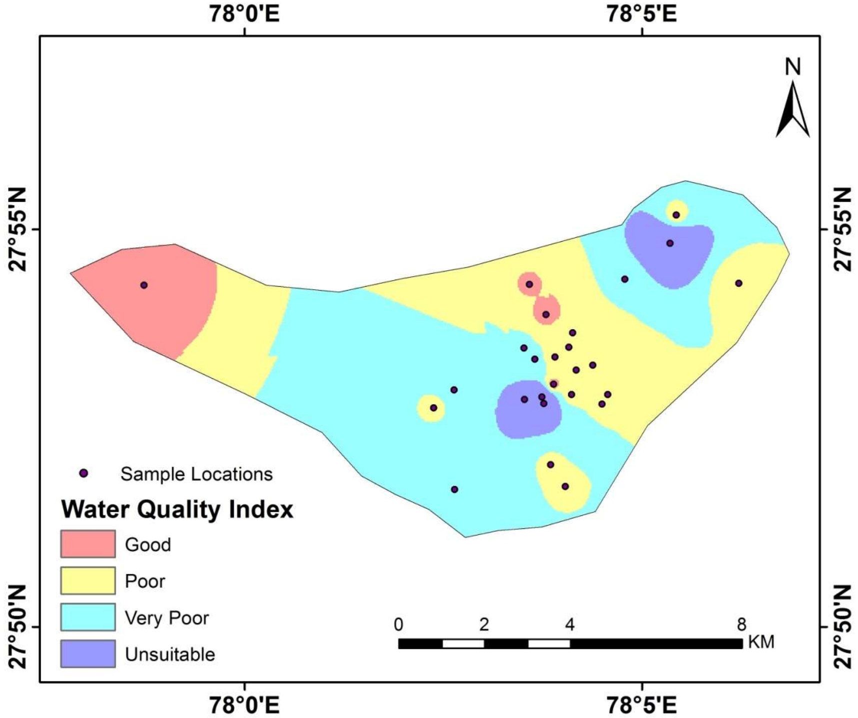

Figure 7. Water quality index of study area in Aligarh District.

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4.5:. Groundwater Quality for Determination of Irrigation Use

The population of the Aligarh area increased several-fold in the recent years. The small-scale farmer uses groundwater for agriculture activities. So determining the groundwater suitability for agriculture activities is necessary and need of the time. Several parameters are employed in this category, the important ones are

(a) Sodium Adsorption Ratio (SAR)

The Sodium adsorption ratio (SAR) is a water quality parameter used for the management of sodium-affected soils. It is an indicator of the suitability of water for agriculture purposes, SAR is calculated as:

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

In the study area, the value of SAR ranges from 0.37 to 11.21 with an average value of 3.62. Mostly samples of the study area are excellent for irrigation**.** (**Table 6**). Using the US salinity diagram classification of irrigation water, the water samples were also examined in order to determine the groundwater quality for irrigation purposes. The majority of groundwater samples fall into the C3-S1, C2-S1 fields, with just a few samples falling into the C3-S2, C3-S3, C1-S1 and C4-S1 categories. The samples have a medium to high salinity hazard and a sodium (alkalinity) hazard. (**Fig.8**)

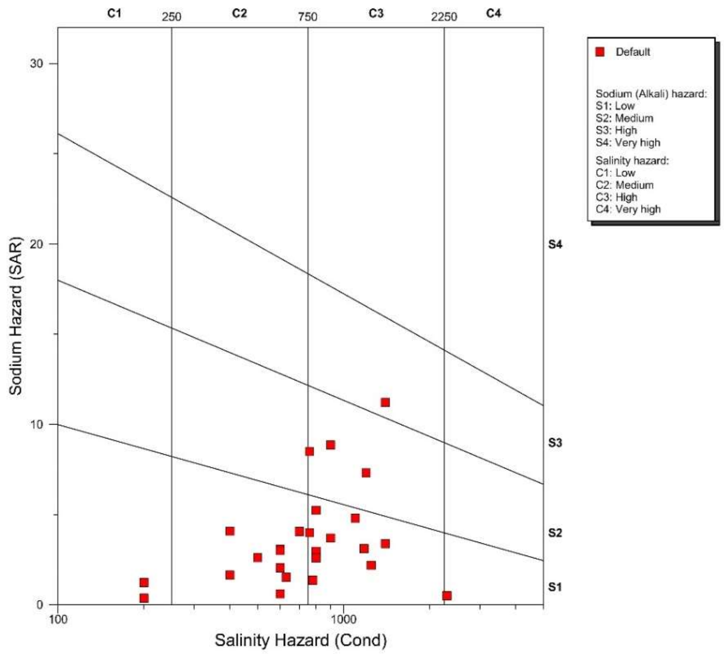

Figure 8. U.S. salinity classification of groundwater for irrigation in the study area.

Table 6. Sodium adsorption ratio range with numbers of sample.

Irrigation parameters	*Range*	*Classification*	*Examined water*
SAR	<10	Excellent	25
	10-18	Good	1
	18-26	Doubtful	None
	>26	Unsuitable	None

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(b) Percent Sodium: Sodium in the soil is viewed as crucial for deciding groundwater suitability for agriculture because Na reacts with soil only to diminish its permeability and support little practically for plant development. Excess sodium in water produces unfortunate impacts of changing soil properties (Wilcox, 1958). Sodium combining with carbonate can lead to the formation of alkaline soils, while sodium combining with chloride form saline soils. The chemical quality of groundwater samples was studied from plots of the percentage of sodium and electrical conductivity on the Wilcox diagram (**Figure. 9**). It is expressed as:

$$SP=\frac{Na^{+}+K^{+}}{Ca^{2+}+Mg^{2+}+N\ ^{+}+K^{+}}\ x\ 100$$

Table 7. Percent Sodium range with numbers of sample.

Irrigation parameters	*Range*	*Classification*	*Number of samples*
	<20	Excellent to Good	4
	20-40	Good to Permissible	6
Percent Sodium	40-60	Permissible to Doubtful	11
	60-80	Doubtful to Unsuitable	4
	>80	Unsuitable	1

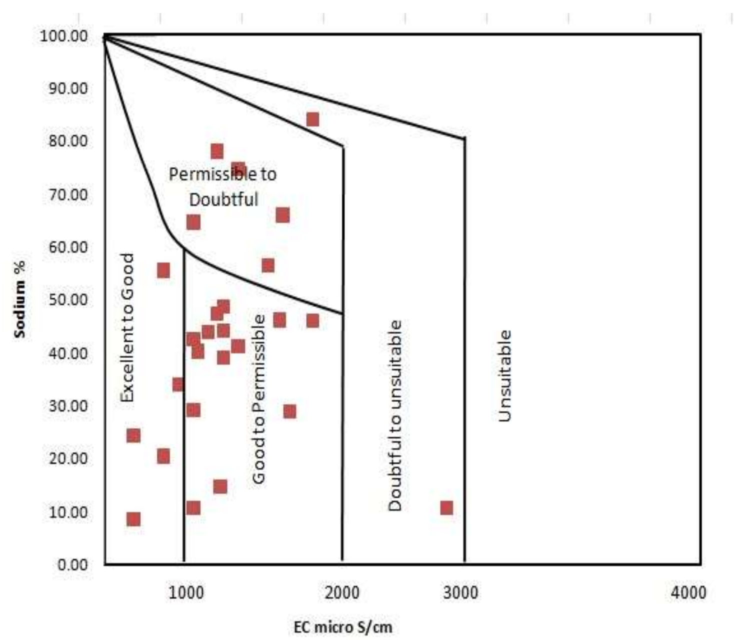

Figure 9. Wilcox diagram for percent sodium vs EC.

(c) Permeability Index (PI)

Doneen(1964)proposed a criterion for assessing the suitability of water for irrigation based on PI. It is classified as:-

$$PI=\frac{Na^{+}+\sqrt{HCO3^{-}}}{Ca^{2+}+Mg^{2+}+Na^{+}}\ x\ 100$$

Water classified as class I is excellent for irrigation and soil demonstrates 100% of most extreme permeability. Water falling into class II is adequate for irrigation and soil has 75% of maximum permeability, and water in class III is inadmissible for irrigation and is related to just 25% of greatest permeability. In **Figure 10**, Sixteen

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samples are of excellent quality for irrigation based on PI and will not affect soil permeability. Nine water samples are acceptable and 1 is unsuitable for irrigation respectively.

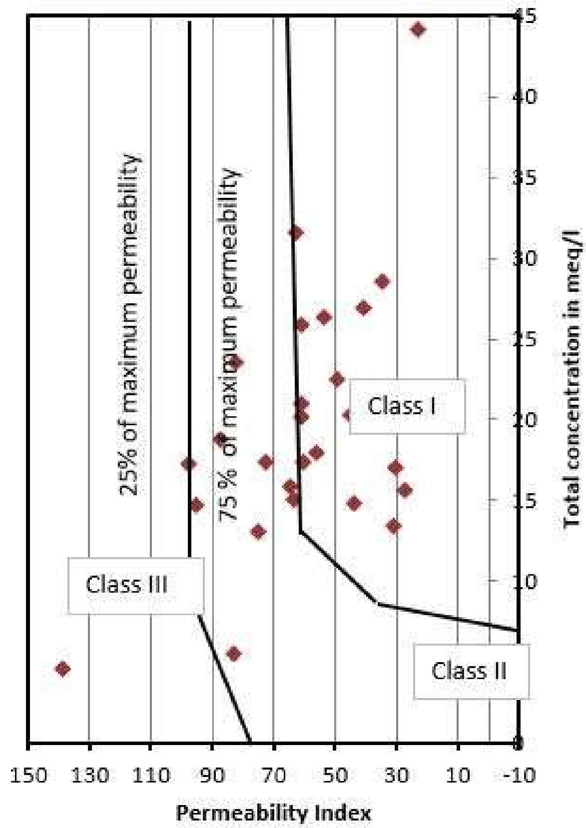

Figure 10. Doneen classification of irrigation water quality based on PI.

(d) Potential salinity: Doneen (1964) clarified that the suitability of water for irrigation isn't subject to dissolvable salts. The low dissolvability salts precipitate in the soil and add with each successive irrigation concentration of highly soluble salts that increase the soil salinity. Potential salinity is defined as the chloride concentration plus half of the sulfate concentration as showed below:

$$PS=Cl^{-} + \frac{1}{2SO4^{2-}}$$

The potential salinity ranges from 1.02 to 14.21 meql^{-1} with an average of 5.50 meql^{-1}. The potential salinity of groundwater samples was classified into 3 classes (**Table 8**):

Table 8. Potential Salinity range with numbers of sample.

Range	*Remarks*	*No. of samples*
<5	Excellent to Good	12
<5 -10	Good to Injurious	13
>10	Injurious to Unsatisfactory	1

It recommends that the potential salinity in the groundwater of the examined area is almost high, subsequently, making the water inadmissible for irrigation usage. High potential salinity value in the

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study region can be attributed to high sulfate and chloride content derived from an anthropogenic source.

(e) Kelly ratio(KR): Kelly (Kelly, 1940)ratio is the ratio of sodium ion to calcium and magnesium ions in meq/L Used to determine the hazardous effect of sodium on water quality. If irrigation water contains a high concentration of Na^{+}, then clay particles absorb Na^{+} displacing Mg^{2+} and Ca^{2+} ion. This exchange process can reduce the permeability of the soil and can ultimately affect the internal drainage (Karanth, 1987) .Kelly's ratio is computed as:

$$KR = \frac{Na^{+}}{Ca^{2+} + Mg^{2+}}$$

Water with Kelly's ratio less than one is suitable for irrigation, while those with a ratio of more than one are unsuitable. From Table 10, it can be suggested that Kelly's ratio varies from 0.07 to 4.77 with an average value of 1.01. In the present study, only 7 water samples are unsuitable for irrigation with more than one of Kelly's ratio.

(f) Residual Sodium Carbonate.

Term RSC was introduced by(Eaton, 1950).The high percentage of HCO_3^{-} and CO_3^{2-} present in groundwater shows property to form a coagulate with Ca^{2+} and Mg^{2+} ions. High RSC values have high pH and are a cause of infertility of irrigation land due to the deposition of sodium carbonate as indicated by the black color of the soil. Lloyd and Heathcote (Lloyd & Heathcote, 1985) proposed a classification for the water used in agriculture based on RSC values. As per this classification, water samples with RSC value less than 1.25 are suitable for irrigation, whereas water with RSC up to 2.5 is marginally suitable and above this water is unsuitable (Table 9).Based on the US Salinity Laboratory, USA, 1954).Residual sodium carbonate calculated as:

$$RSC = (HCO3^{-} + CO3^{-}) - (Ca^{2+} + Mg^{2+})$$

The groundwater samples in the study region show RSC values of -21.54 to 9.97 with an average value of 0.10meql^{-1}(Table10).

Table 9. RSC classification of the study region.

Irrigation parameters	*Range*	*Classification*	*Number of samples*
	<1.25	Good	15
RSC	1.25-2.5	Doubtful	1
	>2.5	Unsuitable	10

Table 10. Different indices value for irrigation purposes in the study region.

Locations	*IBE1*	*IBE2*	*Na %*	*SAR*	*Gibbs II*	*Gibbs I*	*KR*	*PI*	*PS*	*RSC*
Delhi gate	0.85	14.83	44.22	2.97	0.46	0.24	0.72	63.54	3.17	4.84
Kanwariganj	5.19	10.84	40.45	1.52	0.53	0.49	0.59	82.91	5.76	2.46
Talaspur	1.19	9.32	55.65	4.08	0.65	0.33	1.20	74.82	3.55	2.66
Shahjamal	3.00	10.79	78.10	8.49	0.83	0.44	3.34	95.32	5.25	3.38
Bhojpura	13.15	19.66	84.03	11.21	0.86	0.71	4.77	97.71	14.21	2.99
Sarai Sultani	6.92	15.57	47.38	4.00	0.55	0.47	0.85	60.82	8.25	-1.79
Khair Road	7.43	18.00	8.51	0.37	0.09	0.43	0.07	30.91	7.70	-2.26
Gonda Road	6.53	14.36	42.52	3.10	0.44	0.41	0.69	60.62	7.82	1.06
Gudiya Bagh	2.24	14.35	46.02	3.39	0.54	0.30	0.82	64.68	4.14	2.51
Ashok Nagar	1.23	14.13	39.20	2.59	0.45	0.22	0.56	55.94	3.42	0.86
Shaktinagar	6.19	15.76	10.77	0.49	0.14	0.44	0.09	27.18	6.61	-5.85
Rasalganj	0.16	7.35	74.85	8.85	0.96	0.40	2.88	87.35	3.94	1.07
Upper Fort	7.93	19.81	66.09	7.30	0.78	0.37	1.83	82.44	9.76	8.19

Dubey ka padao	3.49	19.35	46.37	3.11	0.54	0.27	0.67	61.01	5.41	5.21
Sasni gate	5.23	17.50	41.19	3.70	0.46	0.37	0.67	53.31	6.88	-3.64
Madar gate	8.30	17.59	56.45	4.80	0.62	0.52	1.23	72.62	9.40	1.11
Mahavirganj	4.87	22.17	28.93	2.19	0.36	0.30	0.35	40.95	6.19	-2.78
Railway road	0.18	23.32	48.72	5.24	0.52	0.16	0.92	62.64	4.08	4.78
Exibition Ground	1.71	23.84	43.97	4.06	0.53	0.17	0.75	60.82	4.41	5.98
ITI road	0.90	16.38	10.75	0.60	0.13	0.14	0.11	30.30	1.97	-0.67
Ramnagar colony	4.31	21.32	14.70	1.37	0.18	0.25	0.16	22.85	5.56	-21.39
Sarai rahman	-0.01	15.79	34.03	2.62	0.39	0.17	0.48	49.30	2.80	-1.20
Nai basti	7.51	20.18	29.20	2.05	0.37	0.41	0.38	45.15	8.27	-2.30
Quarsi	-1.06	19.69	20.49	1.65	0.27	0.10	0.25	34.75	1.99	-4.62
SS nagar	-2.75	11.91	24.41	1.23	0.31	0.08	0.26	44.04	1.02	-0.21
Dhoerra	-0.53	13.93	64.72	3.01	0.74	0.12	1.68	138.65	1.51	10.84

Conclusion

The detailed study of the groundwater sample in the Aligarh city showed that the groundwater sample is unfit for human consumption and requires proper treatment before consumption. The values of the majority of the parameters are beyond the prescribed limit of BIS. Groundwater for irrigation purposes is mostly suitable although few areas are showing higher values in some selected parameters. The unusual high values of some solutes in the groundwater are due to the uncontrolled growth of population and industrializations (mainly lock, food processing industries) and ultimately lead to over-extraction of groundwater resources.

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