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Assessment of Groundwater Quality for Drinking and Irrigation Use in Gurugram Block of Gurugram District, Haryana, India

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Groundwater is a vital and reliable source of water in all climates worldwide. In this work, a total of 26 groundwater samples were collected from the Gurugram Block of Gurugram District (a cosmopolitan city situtated proximately to capital of India) analyzed for electrical conductivity, pH, hardness, dissolved solids (TDS), Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and alkalinity as HCO_3^-, CO_3^{2-}. Based on the analytical results, the sodium adsorption ratio, sodium percentage, residual sodium carbonate, chloro-alkaline index, base exchange index, meteoric genesis index, permeability index), magnesium hazard and Kelly index were calculated. The most abundant cations were Na^+ and Ca^{2+}, which accounted for 43% and 36% of total cations, respectively. Based on median value, the cations are in the following order: $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. There are no dangers in any of the 22 villages (85%). They have fluoride levels which are less than the maximum desirable limit of 1.0 mg/L established by IS: 10500, 2012. There were 15 villages (58%) with nitrate concentrations less than the limit (45 mg/L) and 11 villages (42%) with nitrate concentrations greater than the limit. The conductivity of groundwater samples was dominated by the ions EC-TDS (r = 1.0), EC-Na (r = 0.93) and EC-HCO_3 (r = 0.84). The natural origin of the ions was revealed by the Na-Cl correlation coefficient (r = 0.82). TDS and Na correlated positively (r = 0.93). Wilcox classified that 4% of the ground water samples as excellent to good, 19% as good to permissible, more than 19% as doubtful to unsuitable and 58% as unsuitable for irrigation. According to the US salinity diagram,% of the samples fall into the C3–S1 water class, indicating water with a high salinity hazard and a low sodium hazard.

Keywords: Groundwater, Drinking water, Residual sodium carbonate, Irrigation water, Kelly index, Permeability index, Gurugram.

INTRODUCTION

Globally, groundwater is a vital source of freshwater storage. Groundwater availability is influenced by topography, surface drainage, geology, slope and vegetation. Slope and topographic elevation are major drivers of water table elevation. As a result, the drainage pattern influences the quantity of rain that falls on the ground. Rainfall controls groundwater levels as well as surface permeability. Rock and soil permeability affects groundwater infiltration and retention [1].

The world's total drafted groundwater is used for drinking by approximately 65% of the population, irrigating 20% of farmland, watering animals and industrializing 15% of the population [2]. In India, 89% of groundwater is used for irrigation, 9% for domestic and 2% for industrial purposes [3]. Water shortages in developing countries like India have exacerbated the problem. Rapid population growth, intensive agriculture, rapid urbanization and industrialization have increased the water demand, affecting the quantity and quality of groundwater.

Groundwater quality testing for drinking and agricultural purposes has grown more important. Global studies on the suitability of groundwater for drinking and irrigation [4-7] and irrigation purpose [8-11]. In India, non-selective use of fertilizers, disposal of industrial & household wastes in an unplanned manner and over-exploitation of groundwater are causing degradation in groundwater quality. Various studies in different states of India showed that groundwater of Haryana [12], Uttar Pradesh [13,14], Andhra Pradesh [15], Maharashtra [11,16,17], Karnataka [18], Telangana [1,19] and Kerala [20] was partially fit for irrigation. A globally similar type of study was carried out by Aghazadeh & Mogaddam [21] in the Oshnavieh area of Iran, Ishaku *et al*. [22] in the Jada area of north-eastern Nigeria, Salifu *et al*. [23] in the upper west region of Ghana, Soleimani *et al*. [6] in Sarpol-e Zahab city in Iran, Wu & Sun [5] and Xu *et al*. [24] in Guanzhong plain of China. Highly saline and alkaline irrigation water of these areas degraded the soil quality, which directly affected the fertility of the soil.

In the present research region, there is no systematic and complete data on groundwater quality for drinking and irrigation. The goal of the study was to create a solid database on the quality of groundwater in the study area for drinking and irrigation. Electrical conductivity, sodium percentage, sodium absorption ratio, residual sodium carbonate, chloro-alkaline index, base exchange index, meteoric genesis index, permeability index, magnesium hazard and kelly index were used to determine the suitability of groundwater for irrigation. The groundwater samples were also classified for irrigation using the US salinity, Wilcox diagram and Gibbs plot.

EXPERIMENTAL

Groundwater samples from 26 villages located in the Gurugram block of Gurugram district were collected in the polythylene bottles pre-cleaned with the necessary safety measures and analyzed. The samples were collected from different groundwater sources as hand-pumps, tube-wells and bore-wells. The standing water was pumped out for 10 min before collecting the samples. Sampling was done in 1L prewashed polyethylene bottles. Before each sampling, the bottle was washed 2-3 times with pure water to be sampled to avoid any type of contamination. After sampling, all the samples were brought to the laboratory and kept at 4-8 ºC. Standard analytical methods given by the APHA, 23rd editions [25] were used to determine the pH, electrical conductivity (EC), total dissolved solids (TDS) and concentration of major cations & anions in the water samples. The pH, EC and TDS of the collected groundwater samples were measured within 24 h of sampling using the standard method of APHA (4500H+B for pH, 2510B for EC, 2540C for TDS). The combination electrode ROSS Ultra ORION-8102BNUWP (precision 0.01) was used for pH determination. The EC analysis was done by ORION-013005MD Dura Probe 4 conductivity cell with a conductivity meter (STAR-A212). EDTA titrimetric method was used to analyze the concentration of calcium and magnesium. Sodium and potassium were analyzed through flame emission photometry. Nitrate and fluoride concentrations were analyzed by ion selective electrode (ISE) method. The concentration of carbonate (CO_3^{2-}) and bicarbonate (HCO_3^-) were determined by acid-base titration. Chloride was measured by the argentometric titration method. Sulphate (SO_4^{2-}) was determined through the turbidimetric method using a spectrophotometer. The validity of analytical results was examined through the cation-anion balance equations.

$$E = \frac{\Sigma Cations - \Sigma Anions}{\Sigma Cations + \Sigma Anions} \times 100$$

where, ΣCations = total cations (meq/L) and ΣAnions = total anions (in meq/L).

The sample results, with an error percentage of more than ± 5% were omitted from further study.

Using analytical results, various parameters like chloro-alkaline index (CAI), base exchange index and meteoric genesis index were calculated to know the chemical composition of groundwater due to geological processes. The suitability of groundwater for irrigational uses was evaluated based on electrical conductivity (EC), sodium percentage (Na%), sodium absorption ratio (SAR), residual sodium carbonate (RSC), chloro-alkaline index (CAI), base exchange index (BEI), meteoric genesis index (MGI), permeability index (PI), magnesium hazard (MH) and kelly index (KI). These parameters were calculated using the measured ionic concentration of calcium, magnesium, sodium, potassium, carbonate, bicarbonate, chloride and sulphate in milliequivalents per litre. Various graphical plots *i.e.* US salinity, Wilcox diagram and Gibbs plot were also generated to explain the correlation among different physico-chemical parameters [26-28]. Contour maps of physico-chemical parameters were generated by using the Surfer-11. The mathematical expressions used for the calculation of agricultural parameters are given below:

$$CAI = \frac{Cl^- - (Na^+ + K^+)}{Cl^-} \quad (1)$$

$$\text{Base exchange index} = \frac{Na^+ - Cl^-}{SO_4^{2-}} \quad (2)$$

$$\text{Meteoric genesis index} = \frac{[(K^+ + Na^+) - Cl^-]}{SO_4^{2-}} \quad (3)$$

$$Na\ (\%) = \frac{Na^+ + K^+}{Ca^{2+} + Mg^{2+} + Na^+ + K^+} \times 100 \quad (4)$$

$$SAR = \frac{Na^+}{\left(\frac{Ca^{2+} + Mg^{2+}}{2}\right)^{1/2}} \times 100 \quad (5)$$

$$RSC = (HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+}) \quad (6)$$

$$PI = \frac{Na^+ + (HCO_3^-)^{1/2}}{Ca^{2+} + Mg^{2+} + Na^+} \times 100 \quad (7)$$

$$MH = \frac{Mg^{2+}}{Ca^{2+} + Mg^{2+}} \times 100 \quad (8)$$

$$KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \quad (9)$$

RESULTS AND DISCUSSION

Major ions chemistry: The analytical results of all the physico-chemical parameters for groundwater samples are given in Table-1.

Hydrogen ion concentration (pH): Although the pH of drinking water is not harmful to health, it is an essential operational measure for water quality [29]. Corrosion in the water distribution system can be minimized by altering the pH of

TABLE-1
PHYSICO-CHEMICAL PARAMETERS OF ANALYZED GROUNDWATER SAMPLES

Name of village	pH	EC (µS/cm)	mg/L										
			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}	CO_3^{2-}	HCO_3^{-}	Cl^{-}	SO_4^{2-}	TH	TA	TDS
Badshahpur	7.85	2042	151	64.11	229	22	0	641.6	318.6	87.6	645	534.67	1327
Bilaspur	7.21	3574	271.7	89.98	325.9	35	0	904.8	583.2	143.2	1054	754.00	2323
Bindapur	7.52	1527	100	31.14	195.6	11.3	0	806.6	135.2	49.12	380	672.17	993
Budhera	7.51	1699	122.8	37.63	185.7	22	0	541.8	254.9	66.4	464	451.50	1104
Chandu	7.44	1853	153.9	42.62	185.8	25	0	817.9	193.1	58.72	562	681.58	1204
Gwaliar	7.30	2465	182.9	67.04	220.9	38	0	525	386.2	209.6	737	437.50	1602
Haiderpur	7.13	66	6.9	1.08	2.5	0.5	0	25.76	3.86	10	22	21.47	43
Iqbalpur	7.49	2387	132.8	45.56	260.8	34	0	937.8	193.1	126	522	781.50	1552
Islampur	8.10	1512	118.8	34.08	182.7	32	0	594.1	251.1	15.36	439	495.08	983
Jhund Sarai Viran	7.21	1952	148.8	41.61	197.2	44	0	715.6	247.2	70.24	546	596.33	1269
Kharki Majra Dhankot	7.32	2054	138.3	46.06	192.7	48	0	656.3	289.7	72.32	538	546.92	1335
Naharpur Kasan	7.22	2161	208.7	51.3	205.5	54	0	780.8	444.2	57.6	736	650.67	1405
Nainwal	7.15	2134	218.7	33.61	183.9	44	0	591.8	366.9	92.48	687	493.17	1387
Sadhrana	8.00	1862	160	85	210	55	0	520	520	110	754	433.33	1210
Sehrawan	7.60	1483	140	56	178	43	0	390	400	86	584	325.00	964
Danokri	7.50	1440	130	51	165	46	0	380	400	91	538	316.67	936
Shamshpur	7.70	1877	170	75	190	35	0	450	500	120	738	375.00	1220
Kadarpur	7.10	938	118	31.2	85	32	0	290	180	110	425	241.67	610
Fazalwas	7.50	903	108	33.6	65	25	0	300	190	101	410	250.00	587
Sihi	7.40	763	60	38.4	108	28	0	270	210	95	310	225.00	496
Rathiwas	7.30	495	62	19.2	75	25	0	200	160	55	235	166.67	322
Tikri	7.30	600	72	28.8	95	12	0	210	200	75	300	175.00	390
Wazirpur	7.40	1126	132	33.6	115	31	0	310	300	101	470	258.33	732
Sidhrawali	7.70	1215	152	40.8	125	42	0	390	320	125	550	325.00	790
Kankrola	7.40	1862	80	50.4	110	25	0	400	370	210	410	333.33	1210
Tatarpur	7.10	1042	134	51.2	105	22	0	370	300	105	549	308.33	677

the water. Degradation of the taste and appearance of water is caused by corrosion of water distribution pipelines. Metals are also released into the water, polluting it. Any cracks in the lining of the cement-mortar lined ductile iron pipe cause the pH of the supplied water to be unusually high or low. The pH of the groundwater samples analyzed ranged from 7.10 (Kadarpur) to 8.10 (Islampur), with a mean of 7.44 (alkaline). The WHO and BIS recommend a pH range of 6.5-8.5 for drinking water [30,31]. All of the samples are within the permissible limits.

Electrical conductivity (EC): The capacity of an aqueous solution to carry electricity is determined by its electrical conductivity. It shows the strength of cations and anions in water and a high number indicates that the water is unsafe to consume. EC value of groundwater samples ranged from 66 (Haiderpur) to 3574 µS/cm (Bilaspur). The high EC value (> 2000 µS/cm) groundwater of villages Badshahpur, Bilaspur, Gwaliar, Iqbalpur, Kharki Majra Dhankot, Naharpur Kasan and Nainwal villages showed that various natural factors and anthropological factors were controlling the chemical nature of ground aquifers.

Total hardness (TH): Water hardness is caused by dissolved calcium and magnesium ions. Total hardness (TH) ranged from 22 (Haiderpur) to 1054 mg/L (Bilaspur). Twenty seven (27%) of the study area's samples had TH values above the BIS permissible limit (600 mg/L) and nine (73%) were below it. A water hardness classification (TH 75 mild water; 75-150 moderately hard water; 150-300 hard; and TH > 300 extremely hard) found that just 4% of samples had soft water, 4% had moderately hard water and 92% had very-hard water. The TH values of groundwater samples varied widely. The considerable difference in TH was related to the research area's land use trends. The breakdown of calcium and magnesium ions from sedimentary rocks causes TH in groundwater.

Total dissolved solids (TDS): TDS is an essential criterion for determining whether or not water is fit for drinking. It's the total of dissolved salts' ionic concentrations. The TDS value of water determines its potability. It is inappropriate to consume water that has a very high TDS (metallic flavour) or a very low TDS (insipid taste). TDS value of groundwater ranged from 40 to 2144 mg/at Haiderpur and Bilaspur. All water quality stations had a high TDS value of groundwater. Fifteen samples were within the acceptable limit of BIS for TDS (500 mg/L) but 81% were between the acceptable limit (500 mg/L)-the permissible limit of 2000 mg/L. only 4% of samples exceeded the permissible limit of BIS. This water can be used for drinking in absence of an alternative source.

Calcium and magnesium (Ca^{2+} & Mg^{2+}): In current study area, a range of 6.9 to 271.7 mg/L and 1.08 to 89.98 mg/L were observed for calcium and magnesium ions, respectively. The analysis showed that the concentration of calcium ions in 85% of the samples was above the acceptable limit of BIS (75 mg/L).

Magnesium is an important mineral for humans. At the concentrations seen in unpolluted streams, magnesium has no harmful effects on humans. Humans, on the other hand, Mg^{2+} and SO_4^{2-} ions in drinking water to be laxative. The taste of water with a magnesium content of more than 500 mg/L is unpleasant. In potable water, the BIS sets an acceptable level of 30 mg/L and a permitted maximum of 100 mg/L. The magnesium content of 88% of samples was above the acceptable limit of BIS *i.e.* 30 mg/L and below the permissible limit *i.e.* 100 mg/L. Three samples (12%) collected in the study area had magnesium content within the acceptable value of BIS. Minerals *i.e.* calcite, gypsum and dolomite dissolution cause high calcium and magnesium concentrations in groundwater.

Sodium: The cation exchange of rock minerals determines the quantity of sodium and potassium in groundwater samples. The sodium concentration of groundwater is increased through mineral dissolution, water-rock interaction, agricultural run-off and sewage effluents [32]. The World Health Organization (WHO) recommends a salt taste threshold of 200 mg/L. The kind of associated anion determines the flavoured sodium imparts to drinking water. Alkali metals (Na & K) have a stronger affinity for chloride ions than alkaline metals (Ca & Mg). The sodium content in groundwater samples of the study area was found 2.5-325.9 (min.-max.) mg/L with a mean value of 161 mg/L. Around 23% of samples of Badshahpur, Bilaspur, Gwaliar, Iqbalpur, Naharpur Kasan and Sadhrana villages exceeded the taste threshold for sodium (200 mg/L).

Potassium: Despite the fact that potassium is a critical element for human health, neither the BIS nor the WHO issue any health-based recommendations. Humans require more than 3000 mg of potassium daily. Even after purifying municipal water with potassium permanganate, the level of potassium permanganate is too far low to have any significant health impact. In several situations, potassium chloride is used to soften water. As a result, the potassium level in the water increases somewhat. The potassium concentration in groundwater samples ranged from 0.5 to 55 mg/L at Haiderpur and Sadhrana respectively. The median pie chart of major cations (Na^+, K^+, Ca^{2+} & Mg^{2+}) showed that Na and Ca were dominant cations with 43% and 36% of total cations, respectively. The decreasing order of cations on the basis of median value is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$.

Chloride: Alkali metals and alkaline earth metals are naturally found in groundwater. The contamination of water by industrial and domestic sewage may be linked to a significant rise in chloride concentration. Chlorides and nitrogenous chemicals are abundant in human and animal excrement. Chloride compounds leach into ground aquifers, increasing the chloride level of groundwater. The taste of water is determined by the quantity of chloride compounds in the water. The BIS recommends acceptable chloride limit of 250 mg/L in drinking water. The range of chloride in groundwater samples of the study area was from 3.86 at Haiderpur to 583.2 mg/L at Bilaspur village. Results revealed that samples collected from villages Badshahpur, Bilaspur, Budhera, Gwaliar, Islampur, Kharki Majra Dhankot, Naharpur Kasan, Nainwal, Sadhrana, Sehrawan, Danokri, Shamshpur, Wazirpur, Sidhrawali, Kankrola, Tatarpur (> 250-1000 mg/L) were having chloride concentration higher than the acceptable limit of BIS.

Total alkalinity: Total alkalinity refers to the amount and quality of dissolved chemicals that collectively change the pH to the alkaline side. Sodium, bicarbonate, carbonate, organic acids and hydroxyl ions are all included in this group of cations that are connected with weak bases. However, water has an alkalinity of more than 200 mg/L and consisted of unpleasant taste. Potable water alkalinity levels of 200 mg/L and 600 mg/L were recommended by the BIS. With a mean value of 417.3 mg/L, the total alkalinity of the groundwater in the study region ranged from 21 to 781.5 mg/L. 88% of samples had alkalinity levels over the BIS acceptable limit.

Sulphate: Sulphate in groundwater can come from either natural or man-made sources. Sulphate has no direct health effects, but it gives water a disagreeable taste. Sulphate levels in drinking water should be between 200 and 400 mg/L (BIS). Sulphate concentration in groundwater samples varied from 10 to 210 mg/L and 8% of samples of Gwaliar, Kankrola exceeded the acceptable limit of sulphate prescribed by BIS. The remaining 92% of samples are within the acceptable limit.

Fluoride: The concentration of fluoride varies from 0.08 mg/L (village Haiderpur) to 2.68 mg/L (village Islampur). The study shows 22 villages (85%) in no risk Level-I. These villages have fluoride concentrations below 1.0 mg/L which is the maximum desirable limit of IS: 10500, 2012; standards for drinking water. There is no possibility of fluorosis in these villages. Only one village Bindapur is at low-risk level – II as the fluoride concentration falls in the range of 1.0-1.5 mg/L. According to IS10500, 2012, the maximum permissible limit (MPL) is 1.5 mg/L for fluoride. 11% villages Bilaspur (2.30 mg/L), Iqbalpur (2.25 mg/L), Islampur (2.68 mg/L) which accounts for consume water with a concentration of fluoride ranging from 1.5 to 3.0 mg/L. These villages are at moderate risk level - III. This fluoride concentration leads to dental fluorosis causing loss of shiny appearance on teeth and further deposition of chalky black, grey, or white patches. This condition is called mottled enamel [33]. Spatial distribution of fluoride in the Gurugram block is shown in Fig. 1.

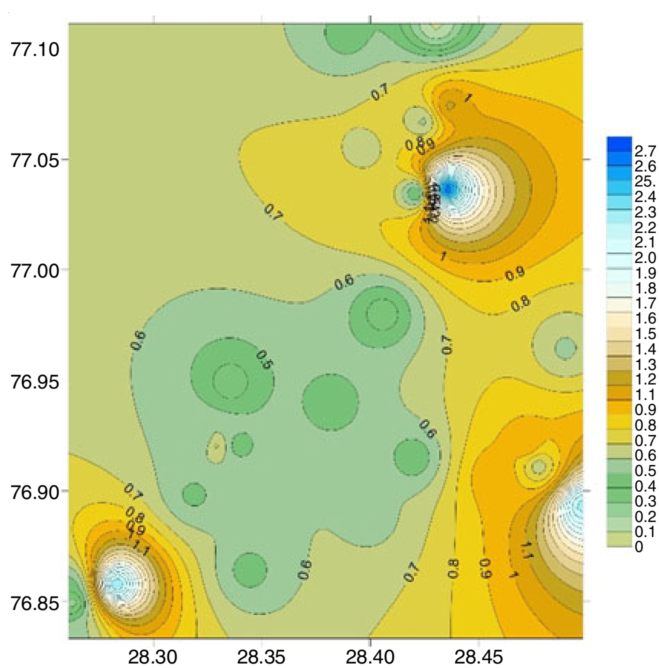

Fig. 1

Nitrate: Based on epidemiological evidence of short-term exposure causing methemoglobinaemia in babies, the IS and WHO have set a recommended guideline for nitrate in drinking water of 45 mg/L [30,31]. The concentration of nitrate varies from 4.04 mg/L (village Haiderpur) to 2.68 mg/L (village Kankrola). Data revealed that 15 villages (58%) had the nitrate concentration (45 mg/L) below the limit and 11 villages exceeded out of 26 villages having the nitrate concentration above the limit. Spatial distribution of nitrate in the Gurugram block is shown in Fig. 2.

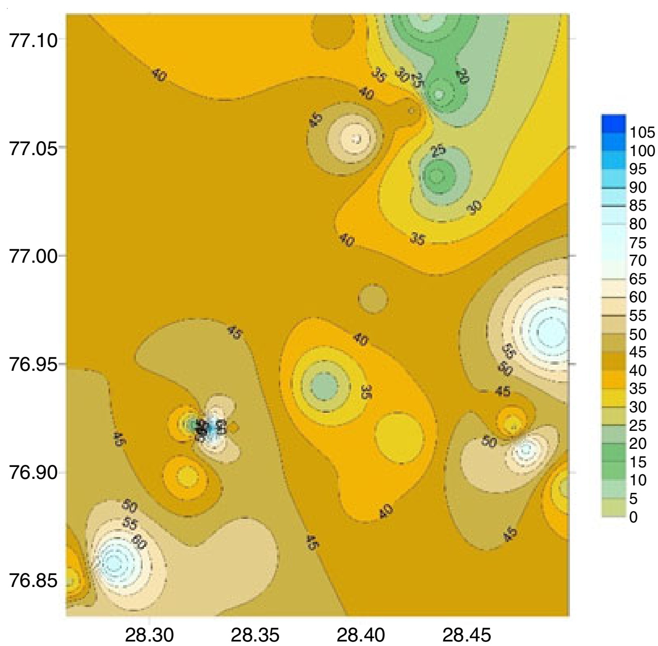

Fig. 2

Correlation analysis: The magnitude of the link between the two variables is described *via* correlation analysis. The correlation coefficient might range from -1 to +1. A correlation of +1 denotes a complete positive relationship between two variables. In contrast, a -1 correlation coefficient indicates that two variables are inversely associated. There is no relationship between the variables if the correlation coefficient is zero. Table-2 shows the Pearson correlation of ten examined parameters of studied groundwater samples. The bold positive correlation coefficient values (r = 0.7) demonstrate the direct positive association between the groundwater parameters.

The EC of the groundwater samples studied was substantially linked with TDS, Ca^{2+}, Na^{+}, Mg^{2+} and HCO_3^- (r = 0.7). The conductivity of groundwater samples was mostly attributable to Na^+, Ca^{2+} and HCO_3^- ions, as evidenced by a significant linear positive correlation between EC-TDS (r = 1.0) EC-Na (r = 0.93) and EC-HCO_3 (r = 0.84). The natural origin of these ions was shown by the correlation coefficient (r = 0.82) between Na^+-Cl^-. There was also a positive association between TDS and Na^+ (r = 0.93).

Suitability of groundwater for irrigation uses: The number of dissolved ions present in groundwater determines its suitability for irrigation. Irrigation water with a high ion concentration has an impact on soil structure and plant development. Salinity danger, salt hazard, alkalinity hazard and boron toxicity are all variables that impact the quality of irrigational water. Electrical conductivity (EC), sodium percentage (Na%), sodium absorption ratio (SAR), residual sodium carbonate (RSC), chloro-alkaline index (CAI), base exchange index (BEI), meteoric genesis index (MGI), permeability index (PI), magnesium hazard (MH) and kelly index (KI) were used to assess the appropriateness of groundwater in Gurugram district. The US salinity [34], Wilcox diagram and Gibbs plot were also used to classify the groundwater samples for irrigation. Table-3 shows the computed values for various parameters.

Electrical conductivity (EC): When using groundwater to irrigate crops, EC is an excellent indicator of salinity. Electrical conductivity is the most essential irrigational water quality factor that affects soil productivity and crop yield. The electrical conductivity of irrigational water is used to assess the risk of water salinity. The soil becomes saline due to irrigation water with a high EC value. The salty soil solution hinders plant development by reducing the root's ability to absorb water from the soil. Physiological drought is the term for this state [35]. Crop irrigation should not be done using very salty water.

Groundwater was classified based on salinity hazard as recommended by Wilcox [27]. It was classified as an excellent (100-250 µS/cm), good (250-750 µS/cm), unsuitable (750-2,250 µS/cm) (Table-4). This sort of water can be utilized for irrigation if it is treated using proper leaching and drainage techniques. Wheat, barley, urd, moong, lentil, gramme, arhar, mustard and other significant crops are grown in the research region. Because these crops had a modest salt tolerance, continuous irrigation with saline water necessitated appropriate

TABLE-2
CORRELATION MATRIX OF PHYSICO-CHEMICAL PARAMETERS OF GROUNDWATER SAMPLES

Parameters	pH	EC	TDS	Ca	Cl	F	HCO_3	K	Mg	Na	NO_3
EC	0.093										
TDS	0.093	1									
Ca	0.018	0.847	0.847								
Cl	0.231	0.686	0.686	0.777							
F	0.416	0.536	0.536	0.321	0.178						
HCO_3	0.139	0.844	0.844	0.67	0.331	0.631					
K	0.172	0.514	0.514	0.649	0.689	0.078	0.359				
Mg	0.321	0.752	0.752	0.719	0.888	0.318	0.472	0.545			
Na	0.264	0.932	0.932	0.787	0.62	0.61	0.883	0.492	0.735		
NO_3	0.003	0.381	0.381	0.264	0.478	0.027	0.118	0.219	0.463	0.23	
SO_4	-0.087	0.437	0.437	0.334	0.511	0.011	0.066	0.254	0.562	0.237	0.471

TABLE-3
IRRIGATION WATER QUALITY PARAMETERS OF ANALYZED GROUNDWATER SAMPLES

Name of village	Base exchange index	Meteoric genesis index	CAI	Na%	SAR	RSC	PI	MH	KI
Badshahpur	-1.02	-0.77	0.21	42.53	3.92	-2.37	57.27	29.80	1.06
Bilaspur	-1.80	-1.55	0.38	39.20	4.36	-6.25	51.77	24.88	0.90
Bindapur	1.23	1.46	-0.53	51.89	4.36	5.63	68.56	23.75	1.49
Budhera	-1.04	-0.71	0.19	45.07	3.75	-0.39	60.38	23.46	1.16
Chandu	-0.12	0.30	-0.09	40.46	3.41	2.16	56.08	21.69	0.95
Gwaliar	-0.79	-0.61	0.33	37.95	3.54	-6.13	51.78	26.82	0.88
Haiderpur	-0.14	-0.09	0.22	19.53	0.23	-0.01	72.28	13.53	0.31
Iqbalpur	0.54	0.81	-0.53	50.07	4.96	4.94	66.36	25.54	1.46
Islampur	-4.45	-2.37	0.14	45.28	3.79	0.96	61.71	22.29	1.20
Jhund Sarai Viran	-0.71	-0.09	0.02	41.60	3.67	0.82	57.78	21.85	1.04
Kharki Majra Dhankot	-1.34	-0.68	0.17	41.15	3.61	0.01	57.90	24.98	1.05
Naharpur Kasan	-4.14	-3.21	0.42	35.70	3.29	-1.91	50.15	19.73	0.79
Nainwal	-1.98	-1.50	0.38	34.98	3.05	-4.03	47.74	13.32	0.73
Sadhrana	-2.82	-2.32	0.49	35.63	3.32	-6.56	51.17	34.69	0.86
Sehrawan	-2.58	-2.08	0.45	37.74	3.20	-5.27	52.87	28.57	0.91
Danokri	-2.58	-2.08	0.47	37.55	3.09	-4.52	53.32	28.18	0.91
Shamshpur	-2.58	-2.29	0.55	34.55	3.04	-7.37	48.55	30.61	0.78
Kadarpur	-0.86	-0.57	0.35	28.39	1.79	-3.75	43.57	20.91	0.57
Fazalwas	-1.24	-0.99	0.53	24.22	1.40	-3.28	39.85	23.73	0.46
Sihi	-1.07	-0.78	0.35	40.43	2.67	-1.77	60.29	39.02	1.10
Rathiwas	-1.55	-1.09	0.38	37.91	2.13	-1.42	57.07	23.65	0.92
Tikri	-1.40	-1.24	0.47	39.57	2.38	-2.56	55.92	28.57	0.94
Wazirpur	-1.83	-1.52	0.51	32.91	2.31	-4.32	47.26	20.29	0.69
Sidhrawali	-1.56	-1.22	0.48	31.04	2.32	-4.61	45.55	21.16	0.65
Kankrola	-1.24	-1.12	0.64	35.11	2.36	-1.64	54.08	38.65	0.84
Tatarpur	-1.86	-1.65	0.58	28.36	1.95	-4.90	42.81	27.65	0.57

All ionic concentrations are meq/L except EC (in µS/cm) and Na %, PI, MH (in percentage).

leaching with extremely porous soil. Irrigation water with an EC value greater than 2250 µS/cm is inappropriate. The measured value of EC in groundwater samples ranged from 66 to 3574 µS/cm with a mean value of 1578 µS/cm. Conductivity of the study area shown in Dot Plot of conductivity (Fig. 3).

Water with an EC value of less than 250 µS/cm, according to Wilcox [27], is excellent for irrigation since it has a high

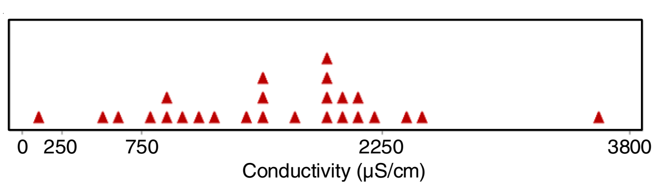

Fig. 3. Dot plot of conductivity (excellent < 250 µS/cm; good 250-750 µS/cm; high saline 750-2250 µS/cm; unsuitable > 2250 µS/cm)

concentration of Ca, Mg and HCO_3 ions. Good for irrigation groundwater has an EC value of between 250 and 750 µS/cm. When the EC value is between 750 and 2250 µS/cm, groundwater is highly saline. With special leaching and drainage methods, this sort of water may be utilized for irrigation.

Because these crops had a moderate level of salt tolerance, extended irrigation with salty water necessitated appropriate leaching with highly porous soil. Irrigation water with an EC value of more than 2250 µS/cm is unsuitable for irrigation. Based on the classification given by Wilcox [27], only 4% were excellent; 8% of samples belong to the good category; around 77% of studied samples were highly saline and 11% of samples were unfit for irrigation purposes.

Chloro-alkaline index (CAI): Geochemical processes can also contribute to the presence of ions in groundwater.

TABLE-4
CLASSIFICATION OF GROUNDWATER SAMPLES BASED ON ELECTRICAL CONDUCTIVITY [Ref. 26]

EC (µS/cm)	Water class	Salinity	Irrigational suitability
< 250	Excellent	Less saline (relatively high proportion of calcium, magnesium & bicarbonate ions)	Perfect for most of the type of crops and any type of soil.
250-750	Good	Moderately saline having varying concentrations of ions	Can be used for crops of salt tolerance with slight leaching. *e.g.* wheat, oats, rice, corn, tomato, cabbage *etc.*
750-2250	Highly saline but can be used under favourable condition	Highly saline (high proportion of sodium & chloride ions)	Can be used for crops of high salt tolerance with specific methods of salinity control. *e.g.* sugar beet, barley, asparagus, spinach *etc.*
> 2250	Unsuitable	Very highly saline (containing high concentrations of sodium, bicarbonate & carbonate ions)	Can only be used in absence of alternative source with highly permeable soil and proper management of drainage.

Lithology, groundwater flow, type of geochemical processes, residence period and salt solubility all impact ion concentrations in groundwater. The ion exchange with the host rock determines the relative concentration of main ions in groundwater. The existence and kind of ion exchange in irrigation water may be confirmed using chloro-alkaline indices. Ion exchange is vital in the regulation of chemical and contaminant movement in irrigation water. Chloro-alkaline index measures the extent of ion exchange between the flowing groundwater and the rocks. Ion exchange between groundwater (Ca + Mg) and rocks (Na + K) is indicated by a negative chloro-alkaline index. A positive chloro-alkaline index indicates reverse exchange process [36]. Only 88% of groundwater samples had a positive CAI (0.02-0.64). On average, ion exchange occurs in 12% of groundwater samples.

Base exchange index & meteoric genesis index: Base exchange index of groundwater signifies whether water is sodium sulphate type or sodium bicarbonate type. According to Soltan [37,38] groundwater with base exchange index < 1 is of sodium sulphate type and groundwater with base exchange index > 1 is of sodium bicarbonate type. In the current analysis, 96% of samples were sodium sulphate type and 4% were of sodium bicarbonate type (Table-5). On the basis of meteoric genesis index, 96% of groundwater samples have the source of deep meteoric water percolation type (meteoric genesis index < 1) and 4% of groundwater samples have the source of shallow meteoric water percolation type (meteoric genesis index > 1). The results showed that most groundwater samples containing sodium sulphate have deep meteoric water percolation sources.

TABLE-5
CLASSIFICATION OF GROUNDWATER SAMPLES BASED ON SODIUM PERCENTAGE [Ref. 27]

Sodium (%)	Water class	Samples (%)
20	Very good	4
20-40	Good	61
40-60	Marginal	35
60-80	Poor	–
> 80	Unsuitable	–

Sodium hazard

Sodium percentage: Sodium hazard or sodicity of water is evaluated in terms of sodium percentage. Sodium content is a key indicator of groundwater irrigation quality. High sodium concentrations cause soil aggregates to disperse, reducing permeability. Wilcox's formula was used to compute the irrigation water's sodium percentage (Na%). Good (20-40%), permissible (40-60%), doubtful (60-80%) and unsuitable (> 80%) were the groundwater classifications given by Wilcox [27]. About 60% is the safest level of salt in irrigation water [35]. A high percentage of sodium in irrigation water results in a decrease in the permeability of soil because sodium ions exchange with calcium and magnesium ions of the soil [39]. Due to the production of Na_2CO_3, the soil becomes alkaline and saline (due to the formation of NaCl). Crops cannot thrive on soil that is too alkaline or saline. The Na% of groundwater samples ranged from 19.53 to 51.89%. According to the classification given by Wilcox [27], 4% of samples belong to a very good type, 61% of samples belong to a good type, 35% fall under the category of marginal type (Table-5).

Sodium absorption ratio (SAR): Sodium absorption ratio is also used to express sodium hazard. SAR is a key metric in determining irrigation water suitability. The sodium absorption ratio is used to assess the alkali or sodium toxicity of irrigation water. SAR measures the impact of increased sodium concentration relative to calcium and magnesium on soil structure. In irrigation water, sodium is adsorbed on soil particles, making it hard and harsh. Long-term usage of SAR-rich water decreases soil permeability and turns it impermeable. SAR-based classifications for groundwater include excellent (SAR 10) and good (10-18) as well as doubtful (18-26) and unsuitable (> 26) [26]. The measured values of SAR of groundwater samples ranged from 0.23 to 4.96 meq/L. According to the classification based on SAR values, 100% of the samples fell into the excellent category.

Bicarbonate hazard

Residual sodium carbonate (RSC): Residual sodium carbonate (RSC) is an indicator used to assess bicarbonate risk and classify water for irrigation. Calcium and magnesium tend to precipitate as carbonates in high bicarbonate water. RSC evaluates the excess of carbonate & bicarbonate ions over calcium & magnesium ions. RSC shows that the carbonate and bicarbonate concentrations are greater than calcium and magnesium. Irrigation water with high carbonate & bicarbonate content precipitates calcium & magnesium ions. Calcium and magnesium precipitation increases the concentration of soil water in the form of Na_2CO_3. The classification of water quality for irrigation based on RSC was proposed by Eaton [40]. Residual carbonate levels less than 1.25 meq/L are considered safe; 1.25-2.50 meq/L are within the doubtful and unsuitable (> 2.5) for irrigation. Based on RSC value, 88% of samples belong to the safe, 4% of samples belong to the doubtful class and 8% of samples of Bindapur and Iqbalpur villages are unsuitable for irrigation (Table-6). Water with an RSC greater than 2.5 meq/L can build up salt, which may obstruct air and water flow by plugging soil pores and degrade soil quality.

TABLE-6
CLASSIFICATION OF GROUNDWATER SAMPLES BASED ON SAR, RSC, PI, MH AND KI

Classification	Water class	Ranges (meq/L)	Samples (%)	Ref.
Sodium absorption ratio (SAR)	Excellent	< 10	100	[25,27]
	Good	10-18	–	
	Doubtful	18-26	–	
	Unsuitable	> 26	–	
Residual sodium carbonate (RSC)	Good	< 1.25	88	[25]
	Medium	1.25-2.50	4	
	Bad	> 2.50	8	
Permeability index (PI)	Class I	> 75%	–	[41,42]
	Class II	25-75%	100	
	Class III	< 25%	–	
Magnesium hazard (MH)	Suitable	< 50%	100	[39]
	Unsuitable	> 50%	–	
Kelly index	Suitable	< 1	69	[40,41]
	Unsuitable	> 1	31	

Permeability index (PI): Doneen [41]& Rao *et al*. [42] proposed the permeability index (PI) to express the impacts of Ca^{2+}, Mg^{2+}, Na^{+}, Cl^{-} and HCO_3^{-} in irrigation water on soil permeability. There are three types of PI: class I (> 75%), class II (25-75%) and class III (25%). Those in classes I and II are suitable for irrigation, however, class III are unsuitable for irrigation purposes. The permeability index of the analyzed groundwater sample ranged from 39.855% to 72.28%. On this basis majority of the analyzed samples, all samples fell under class II.

Magnesium hazard (MH): In water, magnesium and calcium ions are rather stable, but in soil, they behave differently. Szaboles & Darab [43] proposed the term magnesium hazard (MH) to describe the impact of excessive Mg^{2+} in irrigation water on agricultural productivity. The MH values that are 50 are unsuitable for irrigation purposes. A high concentration of magnesium in irrigational water enhances the alkalinity of soil. Magnesium hazard was calculated for analyzed groundwater samples and it ranged from 13.32% to 39.02%. The groundwater samples having magnesium hazard value greater than 50% are unsuitable for irrigation [44,45]. Data reveals that all groundwater samples have magnesium hazard value of less than 50 hence good for agriculture (Table-6).

Kelly index (KI): The Kelley ratio was developed to assess irrigation water quality by comparing sodium ions to calcium and magnesium ions. According to the classification given by Kelly [46,47] irrigation water is acceptable when the Kelley ratio is less than 1, marginally suitable when the Kelly ratio is 1 to 2 and unsuitable when the Kelley ratio is higher than 2. The KI value of analyzed groundwater samples ranged from 0.31 to 1.49 meq/L (Table-2). There are about 69% of groundwater samples in which the KI value falls below 1 and the remaining 31% of samples fall over 1.

Gibbs plot: To better comprehend the interactions among the major mechanisms affecting surface water chemistry, the Gibbs diagram, 1970 is employed. The Gibbs diagram [48] was utilized to investigate the groundwater composition and related aquifer lithological features. The dominant zones of the Gibbs diagram (evaporation, precipitation and rock-water interaction) were studied. Both the anion(I) and cation (I) Gibbs ratios are reported in meq/L as:

$$\text{Gibbs ratio for anion (I)} = \frac{Cl}{(Cl + HCO_3)}$$

$$\text{Gibbs ratio for cation (II)} = \frac{Na^+ + K^+}{(Na^+ + K^+ + Ca^{2+})}$$

According to Gibbs' plot (Fig. 4), rock water activity predominates in all samples, showing that the ions originate from local geological sources. As a consequence, it was possible to determine for the vast majority of the samples whether rock dominance or evaporation dominance existed. In the rock dominance area, there is just one source of water found.

Wilcox's diagram: Wilcox's diagram is used to classify irrigation groundwaters based on their EC and %Na concentration. There are 4% of the 26 groundwater samples fall into the excellent to good category, 19% fall into the good to the permissible category, 19% fall into the doubtful to unsuitable category and 58% fall into the unsuitable category for irrigation (Fig. 5). Fields that are irrigated with water that is either doubt-

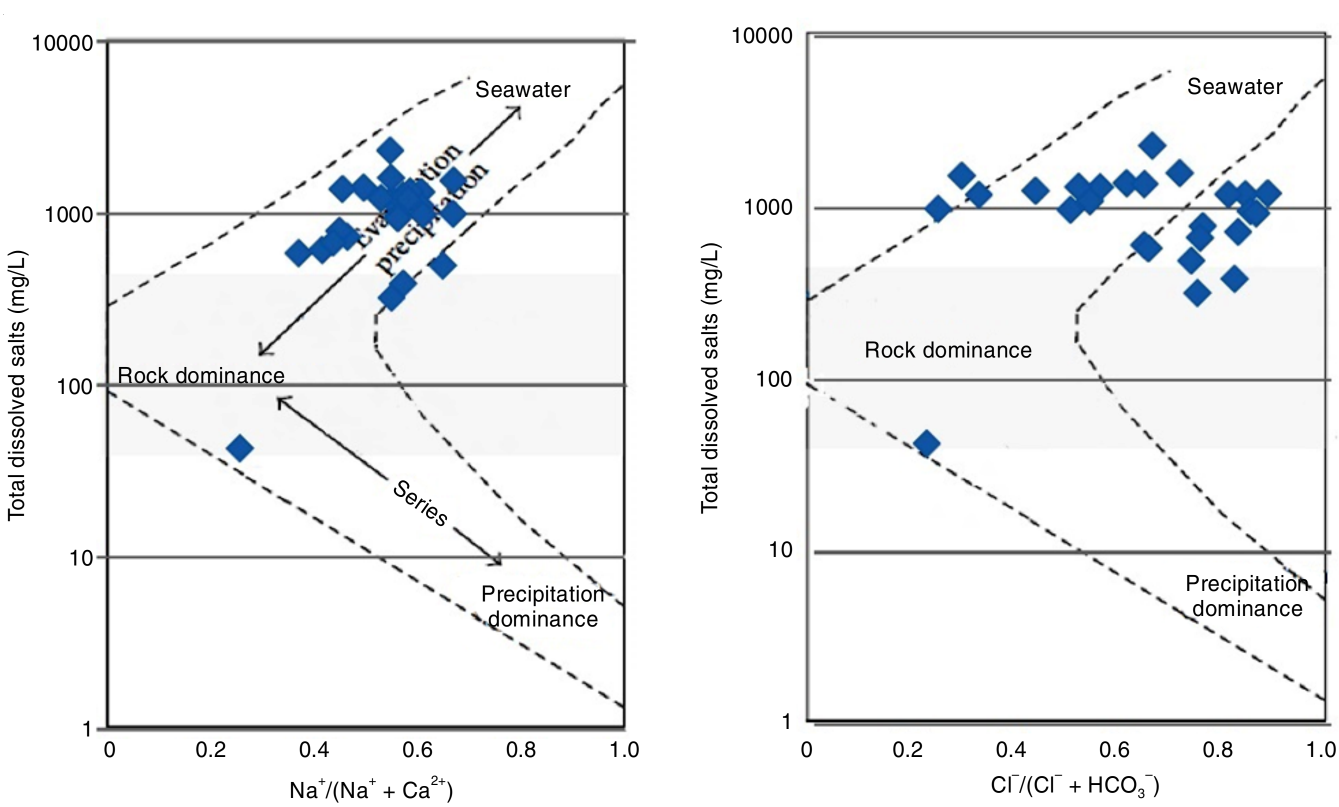

Fig. 4. Gibb's plot of Gurugram block

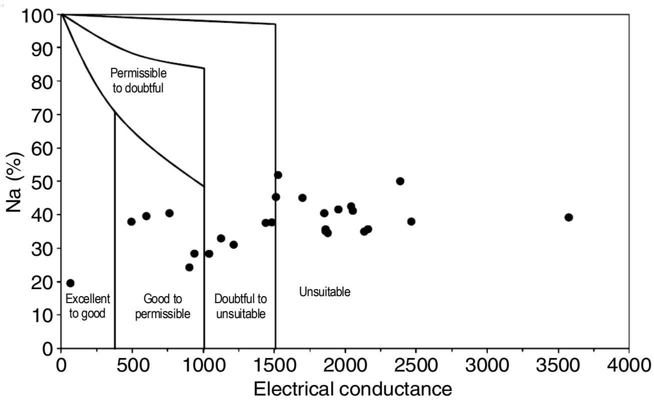

Fig. 5. Water classification in relation to %Na and electrical conductivity (after [Ref. 34])

ful or unsuitable generally provide low yields. Sodium salts, which have an osmotic influence on the soil-plant system, are most likely to blame. It is common for sodium ions to be taken up by clay particles, which in turn removes magnesium and calcium ions from irrigation water. As a result of this Na^+ in water for Ca^{2+} and Mg^{2+} in soil exchange mechanism, soil has poor internal drainage. Wet conditions limit the ability of such soils to dry properly due to their inability to properly circulate both air and water.

US salinity diagram: In addition, EC and SAR were used in conjunction to determine whether or not the water was suitable for irrigation. The US salinity diagram was used to classify the irrigation groundwater samples. In the US salinity diagram, EC represents salinity, whereas SAR represents alkalinity (Fig. 6). 8% of samples had C2S1 quality, medium salinity and low sodium hazard. This groundwater has a C3S1 quality, which means that it has a high salinity risk but a low sodium hazard (80% of the samples). C4S2 and C4S1 quality ground water samples are found in 8% and 4% of the samples, respectively, indicating a very high salinity hazard and a medium sodium hazard, respectively.

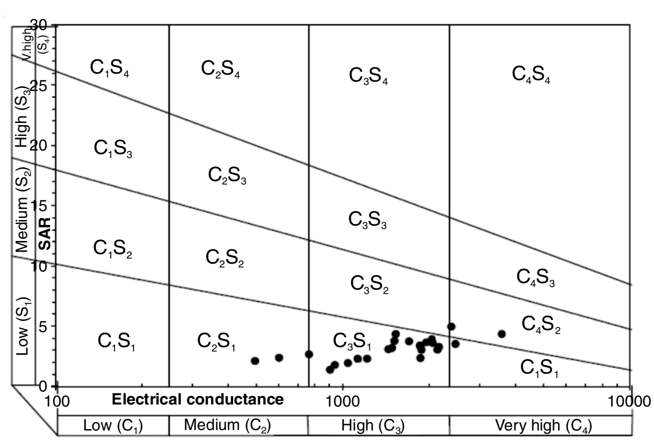

Fig. 6. Salinity and sodium hazard relation for water classification

Conclusion

The suitability of water for drinking and irrigation was assessed on the basis of various water quality parameters. Data revealed that the pH of the groundwater samples varied from 7.10 to 8.44 (alkaline) and all samples are within the permissible limit. The high EC value (> 2000 µS/cm) groundwater of Badshahpur, Bilaspur, Gwaliar, Iqbalpur, Kharki Majra Dhankot, Naharpur Kasan and Nainwal villages of Gurugram District, India showed that various natural factors and anthropological factors were controlling the chemical nature of ground aquifers. 27% of the research area's samples had total hardness values above the BIS permissible limit (600 mg/L) and nine (73%) were below it. This significant variation in total hardness was due to different land use patterns of the study area. 15% samples tested were within the acceptable limit of BIS for TDS (500 mg/L) and 4% of samples exceeded the permissible limit of BIS. Calcium ions ranged from 6.9 to 271.7 mg/L and magnesium ions from 1.08 to 89.98 mg/L in the studied area. The calcium ion concentration in 85% of samples was exceed the BIS limit (75 mg/L). Around 88% of samples had Mg^{2+} concentration over BIS acceptable limit of 30 mg/L. With 43% of total cations, Na^+ and Ca^{2+} were prominent cations in the median pie chart of main cations (Na^+, K^+, Ca^{2+} & Mg^{2+}). The order of cations is $Na^+ > Ca^{2+} > Mg^{2+} > K^+$. Irrigation water with an EC over 2250 µS/cm is unsuitable. According to Wilcox, only 4% of samples were excellent, 8% decent, 77% saline and 11% unsuitable for irrigation. Chloro-alkaline index (CAI) was found in 8% of groundwater samples (0.02-0.64). 13% of groundwater samples had ion exchange. Sodium% varied from 19.53 to 51.89. Wilcox classified samples as follows: 4% excellent, 61% good and 35% mediocre. Exceptional sampling stations (SAR 10). Based on RSC levels, 80% of samples are safe, 4% are doubtful and 8% are unsuitable for irrigation. Over 2.5 meq/L RSC water can salt up, reducing air and water movement and degrading soil. Thus, most of the samples were class II. Magnesium levels in groundwater varied from 13.32 to 39.02. Irrigation-unsuitable groundwater samples have magnesium risks > 50%. No magnesium was found in any of the groundwater samples. Surprisingly, most groundwater samples have KI levels below 1, yet 31% have Kelly index (KI).

CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this article.

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