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Research Article

Evaluation of Groundwater Quality for Suitability of Irrigation Purposes: A Case Study in the Udham Singh Nagar, Uttarakhand

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In the present study, the groundwater quality for suitability in agriculture from Udham Singh Nagar district, Uttarakhand, has been evaluated. A total of 50 groundwater samples have been collected and analysed for pH, EC, TH, HCO_3^-, CO_3^{2-}, Cl^-, SO_4^{2-}, NO_3^-, Ca^{2+}, Mg^{2+}, Na^+ and K^+. To assess the groundwater quality for irrigation purpose, parameters like sodium adsorption ratio (SAR), soluble sodium percentage (SSP), residual sodium carbonate (RSC), magnesium hazards (MHs), permeability index (PI), and chloroalkaline index (CAI) values have been calculated. In USSL diagram, most of the groundwater samples fall in the C2S1 category and were safe for irrigation purpose. Only seven groundwater samples fall in the C3S1 category, indicating medium to high salinity which is safe for irrigation purpose for all types of soils but with limited care of exchangeable sodium. On the basis of RSC, all groundwater samples were observed to be suitable for irrigation purpose. Piper diagram indicated that 50% of the groundwater samples belonged to the Mg^{2+}-Ca^{2+}-HCO_3^- type and 48% was classified as the Ca^{2+}-Mg^{2+}-Cl^- type. Durov diagram suggested possibilities of ion mixing and simple dissolution of ions from polluted soil.

1. Introduction

Groundwater plays an important role all over the world for the survival of both flora and fauna. India is one of the largest users of groundwater, particularly for drinking and agriculture purposes [1] Agriculture is one of the most important sectors of Indian economy. In rural areas, the major sources of groundwater for drinking and irrigation purpose are hand pump and tub well. According to a national sample survey, 56% households get drinking water from hand pump or tube well, 14% from open well, and 25% based on piped water [2]. Groundwater gets contaminated with a variety of pollutants such as domestic, agriculture, and industrial due to utilization of fertilizers, pesticides, and other chemical products [3]. The groundwater quality assessment based on different agriculture indices has been studied in different parts of world [4, 5]. There are a number of reports on the assessment of groundwater quality from Bangladesh [6], Cameroon [7], Ghana [8], Tamil Nadu [9–12], Madhya Pradesh [13, 14], Bhatina, South west Punjab [15] and Sant Ravidas Nagar, Bhadohi, Uttar Pradesh [16]. In Uttarakhand, irrigation water quality assessment has been done in Doon Valley [17], Nainital [18], Almora [19, 20], and Haridwar [21].

To the best of our knowledge, no study on the assessment of irrigation water quality has been undertaken from Udham Singh Nagar District of Uttarakhand with especial reference to dug well and hand pump water. Therefore, in the present study, an attempt has been made to determine the groundwater suitability for irrigation purpose from Udham Singh Nagar district of Uttarakhand.

2. Materials and Methods

Udham Singh Nagar district located in Tarai belt of Kumaun region and geographical area of the district is 3055 cm^2. It is situated between latitude 28°52′N and 29°23′N and longitudes 78°45′N and 80°08′N. The district Udham Singh Nagar covers Champawat and Nainital district in North region of Uttarakhand, south region with Pilibhit, Moradabad, and Bareilly district of UP, and Biznor district of UP on the west and Nepal on the east.

2.1. Collection of Samples. Fifty groundwater samples (hand pump and dug well) were collected in premonsoon season in the year 2018 from different sites of Khatima, Bazpur, Gadarpur, Kashipur, Jaspur Kicha, and Sitarganj blocks of Udham Singh Nagar district, Uttarakhand (Table 1; Figure 1). The samples were collected in prewashed polyethylene narrow mouth bottles (three times rinsed with same water to be sampled). Locations (longitude, latitude, and altitude) of sampling point were measured by using a global positioning system (GPS).

2.2. Chemical Parameters of the Samples. Electrical conductivity (EC) and pH were measured using a potable kit. The water samples were filtered with using 0.45 Millipore membrane filter paper for the separation of suspended solids. Sulphate (SO_4^{2-}) content was determined by the UV spectrophotometric method, while chloride (Cl^-) and bicarbonate (HCO_3^-) content were measured by the titration method [22]. The detection of Ca^{2+}, Mg^{2+}, and total hardness (TH) was done by the titration method, while Na^+ and K^+ were estimated by the flame photometer method [22].

2.3. Evaluation of Irrigation Water Quality. The concentrations of different parameters were interrelated, and irrigation indexes like soluble sodium percentage (SSP), sodium adsorption ratio (SAR), residual sodium carbonate (RSC), magnesium hazard (MH), permeability index (PI), and chloroalkaline index (CAI) were calculated to assess groundwater quality. USSL salinity, Wilcox, permeability index, and Gibbs diagrams were drawn with the help of Grapher free software to assess irrigation quality of collected water samples. Hydrochemical analysis was evaluated by drawing Piper and Durov diagrams using Aquachem (2004) software.

2.4. Salinity and Alkalinity Hazard (SAH). Electrical conductivity and US Salinity Laboratory diagram helped in explaining salinity and alkalinity hazard in the study area.

2.5. Sodium Hazard (SH). Sodium hazard was assessed by evaluating soluble sodium percentage and sodium absorption ratio and drawing Wilcox diagram.

2.5.1. Soluble Sodium Percentage (SSP). Soluble sodium percentage (SSP) was calculated by employing the equation given by Todd [23]. The ionic concentration was presented in meq L^{-1}:

$$SSP = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} \times 100. \quad (1)$$

2.5.2. Sodium Adsorption Ratio (SAR). SAR was calculated using the equation given by Raghunath [24]. The concentration of the ions was expressed in meq L^{-1}:

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}}. \quad (2)$$

2.5.3. Carbonate and Bicarbonate Hazard (CBH). Carbonate and bicarbonate hazard was assessed by evaluating soluble sodium carbonate.

2.5.4. Residual Sodium Carbonate (RSC). This was evaluated employing the following equation of Eaton [25]:

$$RSC = \left(HCO_3^{-} + CO_3^{2-}\right) - \left(Ca^{2+} + Mg^{2+}\right). \quad (3)$$

2.5.5. Magnesium Hazard (MH). This was evaluated by the equation given by Szabolcs and Darab [26], where the concentration of each cation was expressed in meq L^{-1}:

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} \times 100. \quad (4)$$

2.6. Permeability Index (PI). Permeability index (PI) was used to classify the irrigation water quality and was calculated by the formula given by Doneen [27]. The concentration of all ions was taken in meq L^{-1}:

$$PI = \frac{Na^+ + \sqrt{HCO_3^-}}{(Ca^{2+} + Mg^{2+} + Na^+)} \times 100. \quad (5)$$

2.7. Chloroalkaline Index (CAI). Chloroalkaline index (CAI I and CAI II) was calculated by the formula given by Scholler [28]:

$$\text{CAI I} = Cl^- - \frac{(Na^+ + K^+)}{Cl^-},$$
$$\text{CAI II} = Cl^- - \frac{(Na^+ + K^+)}{[SO_4^{2-} + HCO_3^{-} + NO_3^{-} + CO_3^{2-}]}. \quad (6)$$

3. Results and Discussion

3.1. pH. The term pH expressed to describe the intensity of acidic and alkaline nature of a solution. The pH value of the groundwater samples in the study area lie in between 7.57 and 8.61. All the groundwater samples belonged to the safe limit for irrigation purpose [29].

3.2. Water Quality Based on the Absolute Ions. In the present study area, the concentration of cations lies from 20.0 to 140.0 mg L^{-1} for Ca^{2+}, 14.1 to 85.0 mg L^{-1} for Mg^{2+}, 0.4 to 62.0 mg L^{-1} for Na^+, and 0.0 to 55.2 mg L^{-1} for K^+ (Table 2). In irrigation water, the permissible limit for Ca^{2+}, Mg^{2+},

Table 1: Sampling sites along with the coordinates.

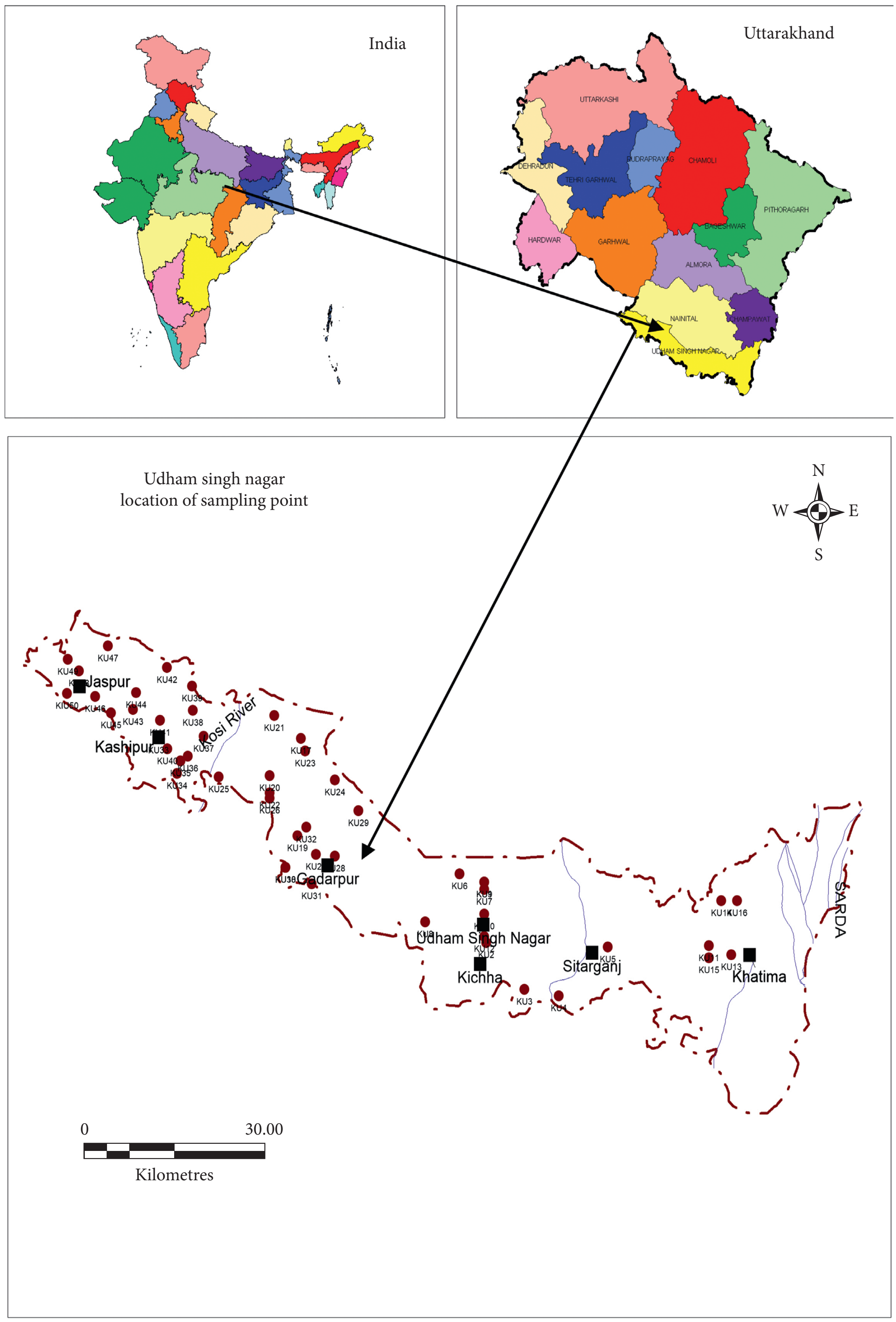
S. no.	Sample location	Block	Source of groundwater	Longitude	Latitude	Altitude (m)
1	Nagla KU1	Rudrapur	HP	29.01861397	79.51723429	174
2	Khurpia KU2		HP	28.93800460	79.52050952	158
3	Bara KU3		HP	28.87547059	79.58577626	151
4	Kathangri KU4		HP	28.86720898	79.64385116	148
5	Baghora KU5		HP	28.93216090	79.72764192	163
6	Haldi KU6		HP	29.02966348	79.47521444	184
7	Matkota KU7		HP	29.00883778	79.40033672	167
8	Dungarpur KU8		HP	29.10925542	79.52622965	235
9	Maharajpur KU9		HP	28.94565023	79.47518752	253
10	Rudrapur KU10		HP	28.97872029	79.39966655	153
11	Turka tishor KU11	Khatima	HP	28.93867576	79.72527877	154
12	Jhankat KU12		HP	28.94002867	79.90025061	162
13	Khatima KU13		HP	28.92166172	79.97217708	155
14	Chakarpur KU14		SS	28.969117	80.01612670	167
15	Pachpera KU15		SS	28.91784380	79.9003284	127
16	Deori KU16		HP	28.99376716	79.92128573	170
17	Barhani KU17	Bazpur	HP	29.20438305	79.20892647	184
18	Seekaniya KU18		HP	29.03828582	79.17878673	150
19	Maseet KU19		HP	29.08021447	79.19893901	163
20	Bazpur KU20		HP	29.15936853	79.15165552	174
21	Bannakhera KU21		SS	29.24025916	79.15940395	196
22	Hazeera KU22		HP	29.19309604	79.21226626	189
23	Gumsani (KU23)		HP	29.13447556	79.15176307	177
24	Mohali jungle KU24		HP	29.15465869	79.26299815	180
25	Sultanpur patti KU25	Gadarpur	SS	29.15738948	79.06430293	168
26	Gularbhoj KU26		HP	29.11357514	79.30314093	165
27	Gadarpur KU27		HP	29.05569688	79.23079049	166
28	Dinehpur KU28		SS	29.05331738	79.32256362	176
29	Gularbhoj KU29		HP	29.11357514	79.30314093	165
30	Singhali KU30		HP	29.2178301	79.17684401	201
31	Jhagarpuri KU31		HP	29.06149689	79.2233027	160
32	Fatehganj KU32	Kashipur	HP	29.09195119	79.21388612	177
33	Mandua Khera KU33		HP	29.13092602	78.94894251	162
34	Kanakpur KU34		SS	29.16310206	78.97692242	173
35	Kanchnal Gosai KU35		HP	29.17990566	78.98805976	169
36	Nandrampur KU36		HP	29.1864069	79.0160997	178
37	Dhakia Kalan KU37		HP	29.20987463	79.0391834	165
38	Bhimnagar KU38		SS	29.24697166	79.0273784	188
39	Chandpur KU39		SS	29.27920450	79.01905650	199
40	Chaity more KU40		HP	29.19604884	78.977699178	176
41	Manpur KU41		HP	29.23402707	78.96438855	169
42	Hempur kechari KU42	Jaspur	HP	29.30418079	78.97646790	229
43	Bharatpur KU43		HP	29.24817043	78.91853846	186
44	Karanpur KU44		HP	29.27077540	78.92668359	186
45	Haldua KU45		SS	29.24366721	78.88074054	183
46	Narayanpur KU46		HP	29.26560579	78.85106087	187
47	Patrampur KU47		HP	29.33296726	78.87312241	211
48	Mandua Khera KU48		HP	29.29226677	78.82597353	190
49	Birpuri KU49		SS	29.31519877	78.82405974	186
50	Kasampur KU50		SS	29.26969627	78.80603843	187

HP = hand pump; SS = summer savil.

Na^+, and K^+ is 80, 35, 200, and 30 mg L^{-1}, respectively [30, 31]. On the basis of these permissible limits, 96% groundwater samples for Ca^{2+}, 42% for Mg^{2+}, 100% for Na^+, and 100% for K^+ were fit for irrigation purpose.

The permissible limit for anions HCO_3^- and Cl^- is 250 mg L^{-1} [30, 31]. The values of HCO_3^- and Cl^- in the groundwater samples varied from 29.2 to 372.0 mg L^{-1} and 8.2 to 252.4 mg L^{-1}, respectively (Table 2). The results on major anions revealed that 64% water samples as per the limit of HCO_3^- and 98% as per the limit of Cl^- were observed to be fit for irrigation purpose.

3.3. Total Hardness (TH). In water quality, TH is an important parameter whether it has been used for domestic,



● Sampling point

Figure 1: Location map of the sampling sites.

irrigation, and industrial purpose. The presence of alkaline Earth metals causes hardness of water which prevents the lather with soap and increases the boiling point. Amount of calcium and magnesium ions in some of the collected samples was high. When calcium reacts with water, either $CaCO_3$ is formed in the form of limestone and chalk, or

$CaSO_4$ is formed. The major source of Mg in groundwater is dolomite, $CaMg(CO_3)_2$. According to Sawyer and McCarthy (1967) [32], water can be categorized as soft (>75 mg L^{-1}), moderately hard (75 to 150 mg L^{-1}), hard (150 to 300 mg L^{-1}), and very hard (above 300 mg L^{-1}). In the present study, TH varied from 155 to 539 mg L^{-1}, indicating hard to very hard nature of water. Thirty-nine samples had hard category, while 20% samples (11 samples) had hardness higher than 300 mg L^{-1}, which is a desirable limit for drinking purpose (Table 2).

3.4. Salinity and Alkalinity Hazard (SAH). The groundwater becomes saline if high salt content is present. The evaluation of salinity hazard is an important parameter of agriculture water as high salt content of irrigation water causes the soil to become saline, and it also adversely affects the salt intake efficiency of the plants. Electrical conductivity (EC) and total dissolved solid (TDS) values are measure of salinity hazard of irrigation water. In the present study, the values of EC and TDS ranged from 353 to 1274 μS^{-1} cm^{-1} and 229 to 828 mg L^{-1}, respectively (Table 2). According to the limiting value [33] of TDS for water suitability for irrigation purpose, 28% groundwater samples belonged to the moderate category. Furthermore, the classification and distribution of groundwater samples with respect to salinity (EC) is given in Table 3. The water samples were classified into four groups on the basis of salinity [34]. Irrigation water quality based on salinity indicated that no water sample belonged to the excellent category (C1). Eighty-six percent of the samples belonged to the C2 class, and remaining 14% was found in the C3 class. On the basis of salinity, none of the samples were observed to be unfit for irrigation purpose.

3.5. United States Salinity Laboratory (USSL) Diagram. USSL diagram has been used to study the quality of groundwater suitability for irrigation purpose [35]. The SAR and EC values of water samples of Udham Singh Nagar District were plotted in the graphical representation (Figure 2) and found that 43 samples fall in C2S1 (medium salinity with low sodium category) and remaining 7 samples fall in C3S1 (high salinity and low sodium category). C3S1-type water cannot be used on soil with restricted drainage. Bhandari and Joshi (2013) reported that 98% of spring water samples from Almora district of Uttarakhand fall in C1S1, which indicated suitability of these samples for irrigation purpose [36].

3.6. Wilcox Diagram. Wilcox diagram is plotted for classification of water for irrigation suitability [37]. In this diagram, the EC was plotted against the percentage of Na. According to Wilcox classification, 86% of the water samples belonged to the excellent good category and remaining 14% groundwater samples fall in good category (Figure 3). Bahukhandi et al. [21] assessed ground and surface water quality of Hardwar district, Uttarakhand, and observed that, according to the US salinity diagram, most of the ground and surface water samples fall in C1S1 and C2S1 categories, while according to Wilcox diagram, large number of water samples was within excellent to good category [38].

3.7. Sodium Hazard (SH)

3.7.1. Sodium Adsorption Ratio (SAR). According to Gholami and Srikantaswamy [39], the alkali or sodium hazard can be expressed in terms of sodium adsorption ratio. Sodium hazard is the main parameter for assessment of groundwater suitability for irrigation purpose. Sodium-enriched groundwater is unsuitable for irrigation of agricultural lands. Biswas et al. [40] reported that excess sodium in water produces undesirable effect of changing soil permeability and water infiltration due to breakdown in the physical structure of the soil. In a previous study, the SAR values ranging from 0 to 10 were measured as excellent, 10–18 were measured as good, and values greater than 18 were measured as unsuitable for irrigation purpose [41]. In the present study, the SAR values ranged between 0.01 and 1.49 and, thus, were classified as the S1 level, which belonged to an excellent category for irrigation purpose (Table 4). Shahidullah et al. reported groundwater quality of Mymensingh district in Bangladesh and suggested that there was a linear relationship between sodium adsorption ratio (SAR) and soluble sodium percentage (SSP) and also observed that groundwater could be safely used for long-term irrigation purpose [42]. Dudeja et al. have also reported that the groundwater of Doon valley in outer Himalaya, Uttarakhand, had suitability for drinking and irrigation purpose [17]. Seth et al. studied that Kosi river water in Almora district, Uttarakhand, could not be used for drinking purpose, while it was found to be suitable for irrigation purpose on the basis of SAR, %Na, and RSC [20].

3.7.2. Soluble Sodium Percentage (SSP). According to Nagarju et al., the percentage of soluble sodium is an important parameter in classifying irrigation water in terms of soil permeability [43]. Sodium ion present in irrigation water tends to be exchanged by Mg^{2+} and Ca^{2+} ions present in clay particles. This exchange process reduces the permeability of soil and causes poor internal drainage and hardening of soil, which further adversely affects the soil quality and seedling emergence [44]. Additionally, high levels of sodium encourage combination of sodium with chloride and carbonates generating salinity and alkalinity in soils. Excessive soil salinity and alkalinity are harmful for plant growth and crop productivity. The classification of irrigation water based on soluble sodium percentage (SSP) is given by Todd [45]. He classified the irrigation water quality into 5 categories (excellent, good, permissible, doubtful, and unsuitable). In the present study, the soluble sodium percentage varied from 0.3 to 35.4%, which suggested that all the groundwater samples had excellent to good quality for irrigation purpose (Table 4).

3.7.3. Residual Sodium Carbonate (RSC). The quantity of carbonate and bicarbonate surplus to that of alkaline Earth

Table 2: Chemical parameters of the collected water samples from Udham Singh Nagar district.

Sampling location	pH	EC (μS cm^{-1})	TH (mg·L^{-1})	Cl^- (mg·L^{-1})	HCO_3^- (mg·L^{-1})	SO_4^{2-} (mg·L^{-1})	NO_3^- (mg·L^{-1})	CO_3^{2-} (mg·L^{-1})	Ca^{2+} (mg·L^{-1})	Mg^{2+} (mg·L^{-1})	Na^+ (mg·L^{-1})	K^+ (mg·L^{-1})	TDS (mg·L^{-1})
KU1	7.79	1131	444	127.0	338.3	82.7	19.39	0	58.8	72.2	62.0	27.0	735
KU2	7.99	1274	539	252.4	356.7	16.7	22.59	0	140.0	46.0	42.0	1.6	828
KU3	8.49	416	207	18.4	196.0	23.8	0.01	9	32.0	31.0	18.0	1.2	270
KU4	7.71	515	237	28.4	230.0	18.9	0.32	0	42.0	32.0	18.3	1.0	335
KU5	8.32	692	277	72.0	295.2	22.7	0.01	3	50.0	50.0	20.0	5.6	450
KU6	7.92	533	255	13.0	237.0	25.2	9.82	0	42.0	36.5	10.0	12.0	346
KU7	7.97	372	444	22.7	153.0	19.0	5.00	0	40.0	18.8	9.0	1.7	242
KU8	8.41	401	383	14.2	159.9	29.0	8.74	6	42.0	24.0	7.2	1.6	261
KU9	7.79	390	169	43.0	129.2	21.6	0.85	0	44.0	18.0	8.3	0.9	254
KU10	7.57	666	263	31.2	256.0	58.4	19.48	0	58.0	32.0	41.0	6.4	433
KU11	8.32	744	286	144.6	176.0	47.2	10.12	3	46.0	34.0	47.0	2.1	484
KU12	8.05	1022	335	113.4	316.0	66.9	54.66	0	38.0	85.0	12.5	0.0	664
KU13	8.22	810	400	51.1	322.0	40.9	0.48	0	82.0	40.0	34.0	1.1	527
KU14	8.16	401	275	34.0	162.5	16.4	0.07	0	50.0	14.1	12.0	1.3	261
KU15	8.45	545	339	28.4	245.0	0.2	0.06	9	28.0	47.0	8.4	0.7	354
KU16	8.36	645	280	26.0	279.0	28.2	1.34	3	52.0	38.0	23.4	9.5	419
KU17	8.57	705	350	35.5	166.1	124.7	0.73	12	60.0	45.0	24.8	1.4	458
KU18	7.97	850	504	76.6	325.0	43.8	0.64	0	30.0	79.0	19.8	1.3	440
KU19	7.79	766	275	70.9	228.0	86.4	5.54	0	52.0	35.2	31.5	12.3	498
KU20	8.4	955	239	14.2	291.0	150.0	19.47	3	70.0	40.0	39.5	55.2	621
KU21	7.86	750	275	22.7	360.0	19.3	45.97	0	54.0	35.2	30.0	12.4	488
KU22	8.39	755	200	14.18	372.0	37.7	5.50	3	48.0	55.9	13.6	0.8	491
KU23	8.25	710	360	19.85	237.0	78.1	0.07	0	50.0	35.2	37.6	12.4	462
KU24	8.35	645	290	17.01	322.0	39.2	0.02	3	46.0	38.0	12.6	1.1	419
KU25	8.06	481	224	19.85	173.0	57.7	5.23	0	56.0	24.2	12.4	0.7	313
KU26	7.94	530	285	14.18	241.0	30.0	3.79	0	60.0	30.4	0.4	0.0	345
KU27	8.33	460	259	11.34	233.7	8.7	5.73	3	40.0	24.3	16.3	1.3	299
KU28	7.76	741	240	8.5	229.0	150.4	0.00	0	48.0	58.3	11.9	1.3	482
KU29	8.38	635	190	28.36	288.0	30.2	0.12	6	60.0	34.0	12.0	1.3	413
KU30	8.3	614	165	25.52	274.0	52.6	1.13	0	36.0	32.6	29.7	1.1	399
KU31	8.15	602	200	25.52	233.0	49.6	0.08	0	40.0	45.0	19.4	1.5	391
KU32	8.32	487	200	70.9	187.0	1.4	0.15	3	32.0	28.3	16.1	1.2	317
KU33	8.6	611	261	17.01	233.0	19.4	29.00	15	40.0	38.7	31.4	1.3	397
KU34	8.11	579	260	34.04	187.0	52.3	0.22	0	56.0	24.3	30.0	1.5	376
KU35	7.95	390	220	19.85	172.0	11.2	0.56	0	44.0	19.4	9.8	1.6	254
KU36	7.87	353	436	25.52	150.0	8.8	5.04	0	38.0	17.0	7.5	0.9	229
KU37	8.08	392	155	25.52	157.0	11.7	6.36	0	36.0	26.7	7.5	0.8	255
KU38	8.23	413	200	19.85	190.7	6.0	0.15	0	40.0	24.3	11.9	1.3	268
KU39	8.59	690	215	130.45	180.0	5.9	0.07	12	46.0	35.6	18.6	11.3	449
KU40	8.23	540	240	14.18	258.3	17.6	4.58	0	52.0	31.6	11.0	0.6	351
KU41	8.13	576	230	19.85	249.0	6.8	37.12	0	56.0	19.4	34.4	1.3	374
KU42	7.75	920	198	130.45	258.0	55.8	0.18	0	94.0	48.8	15.3	1.0	598
KU43	8.61	467	221	28.36	196.8	1.3	2.48	12	20.0	25.5	38.5	1.0	304
KU44	8.04	555	160	24.81	264.5	1.6	0.37	0	46.0	20.7	48.5	1.0	361
KU45	8.42	520	159	11.34	246.0	27.9	9.19	6	38.0	29.2	20.8	1.5	338
KU46	8.45	600	349	28.36	233.0	33.0	13.00	6	52.0	26.7	41.8	0.8	390
KU47	8.46	540	360	34.03	215.2	6.6	7.13	6	36.0	34.0	22.1	1.0	351
KU48	8.2	520	165	22.68	283.0	5.4	0.12	0	48.0	19.0	24.1	0.4	338
KU49	8.16	560	198	24.1	313.0	0.4	4.14	0	42.0	28.2	19.3	1.5	364
KU50	8.55	395	221	28.3	161	0.2	0.12	0	30.0	20.6	24.3	1.2	257

metal ions (Ca^{2+} and Mg^{2+}) also influences the suitability of groundwater for irrigation purpose [37]. This surplus amount of carbonate and bicarbonate is called residual sodium carbonate (RSC). Higher RSC values indicate that much of the calcium and some magnesium ions get precipitated from the solution, and thus, the percentage of sodium increases in water and soil particles, which in turn increases the potential for sodium hazard. The RSC values of the collected water samples varied in between −4.92 and 0.72 meq L^{-1}. Based on the RSC values, all samples were found to be safe for agriculture purpose (Table 5).

3.8. Magnesium Hazard (MH). In the natural water system, magnesium and calcium maintain a state of equilibrium. High value of any one of the cations can increase soil pH and

Table 3: Classification and distribution of water quality based on salinity.

Level	Salinity (μS cm^{-1})	Hazards and limitation	Number of samples
C1	<250	Low hazards and no detrimental effects on the plants and no accumulation in soil is expected	No
C2	250–750	Stress can be shown by sensitive plants, and salt accumulation in soil can be prevented due to moderate leaching	43 samples
C3	750–2250	Most plants affected by salinity (salt-tolerant plants are needed), careful irrigation, good drainage, and leaching required	7 samples (KU1, KU2, KU12, KU19, KU20, KU21, and KU42)
C4	>2250	Unsuitable for irrigation except some highly salt-resistant plants, excellent drainage, frequent leaching, and intensive management required	-

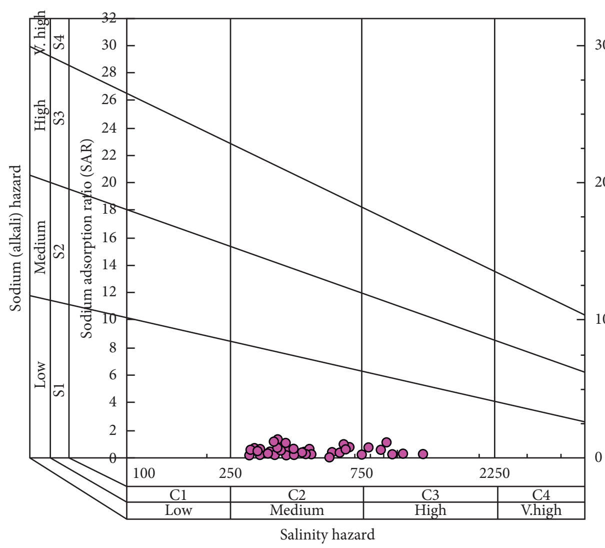


Figure 2: USSL salinity diagram indicating classification of water for irrigation.

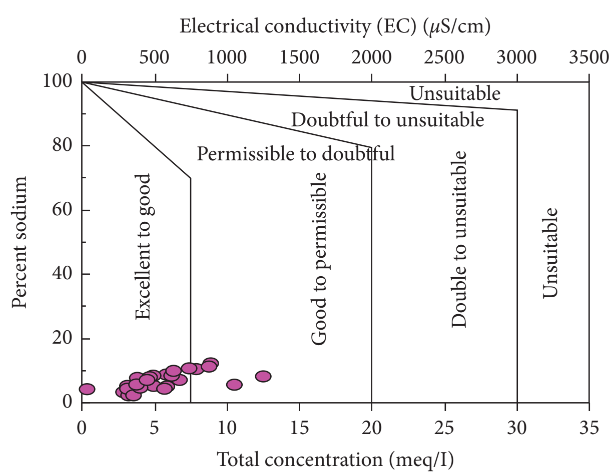


Figure 3: Wilcox diagram showing classification of water for irrigation on the basis of percent sodium and EC.

reduces infiltration capacity of soil, which adversely influences the crop yield. As the content of magnesium was found to be high in the collected samples, magnesium hazard was evaluated in this study. If the value of magnesium hazard is more than 50%, the soil becomes alkaline and its opposite impact on crop yield can be observed [46].

According to Khodapanah et al., the water samples with MH values higher than the 50 are unsuitable for irrigation [36]. In the present study, MH values varied from 32 to 81, which indicated that 56% samples had MH values more than 50. In the study area, the elevated amount of magnesium might be due to dissolution of dolomite. In a study from

Table 4: Calculated parameters of irrigation water quality.

Collection Sites	SAR	RSC	SSP	MH	PI	CAI I	CAI II	Gibbs 1	Gibbs 2
KU1	1.27	−3.33	27.6	67	43.66	2.6369	3.0698	0.60	0.27
KU2	0.78	−4.92	14.8	35	33.70	6.8758	6.8213	0.24	0.41
KU3	0.54	−0.63	16.4	61	52.24	−1.0530	0.2828	0.38	0.09
KU4	0.52	−0.96	14.8	56	49.56	−0.2270	0.5931	0.31	0.11
KU5	0.48	−1.67	13.3	62	41.05	1.5321	1.8314	0.34	0.20
KU6	0.27	−1.21	12.7	59	43.51	−1.6560	0.1922	0.34	0.05
KU7	0.29	−1.03	10.9	44	44.08	0.0401	0.4821	0.21	0.13
KU8	0.22	−1.25	8.0	49	44.98	0.4823	0.2825	0.17	0.08
KU9	0.27	−1.56	9.5	40	52.42	0.8963	1.0496	0.17	0.25
KU10	1.07	−1.33	26.1	48	52.45	1.3332	0.4910	0.45	0.11
KU11	1.28	−2.11	29.2	55	29.89	3.5656	3.4773	0.52	0.45
KU12	0.26	−3.71	5.8	79	42.62	3.0301	3.1164	0.25	0.26
KU13	0.77	−2.10	17.0	45	51.57	0.3935	1.1760	0.30	0.14
KU14	0.38	−0.99	13.2	32	42.09	0.3821	0.7633	0.21	0.17
KU15	0.22	−0.95	6.8	73	46.84	0.3209	0.7046	0.25	0.10
KU16	0.60	−1.05	18.1	55	35.12	−0.9856	0.4751	0.39	0.09
KU17	0.59	−3.57	14.3	81	35.78	−0.1145	0.7233	0.30	0.18
KU18	0.43	−2.67	10.1	53	48.13	1.7459	2.0054	0.41	0.19
KU19	0.82	−1.76	23.5	49	45.9	1.1576	1.6411	0.46	0.24
KU20	0.93	−1.91	25.6	52	54.14	−7.7824	−0.0790	0.57	0.05
KU21	0.78	0.31	22.5	66	40.36	−1.8956	0.3933	0.44	0.06
KU22	0.31	−0.79	8.0	54	51.31	−1.1301	0.3065	0.23	0.04
KU23	0.99	−1.51	25.6	58	47.67	−2.9227	0.1445	0.50	0.08
KU24	0.33	−0.04	9.6	42	41.79	−0.7210	0.3716	0.23	0.05
KU25	0.35	−1.95	10.4	45	36.39	−0.4352	0.4003	0.01	0.10
KU26	0.01	−1.54	0.3	50	56.68	−0.3561	0.3960	0.31	0.06
KU27	0.50	−0.06	15.7	67	31.85	−2.0005	0.1333	0.22	0.05
KU28	0.27	−3.44	7.1	48	42.68	−2.0577	0.1363	0.18	0.04
KU29	0.31	−0.87	8.7	60	59.12	0.1060	0.6898	0.46	0.09
KU30	0.86	0.01	22.8	65	42.80	−1.1137	0.4585	0.34	0.09
KU31	0.50	−1.87	13.4	69	53.00	−0.5056	0.5164	0.35	0.10
KU32	0.50	−0.76	21.3	61	50.73	1.6345	1.7628	0.45	0.27
KU33	0.84	−0.86	21.9	42	50.11	−2.4359	0.1563	0.36	0.07
KU34	0.84	−1.73	11.0	42	49.88	−0.4387	0.5884	0.21	0.15
KU35	0.31	−0.98	9.6	55	52.32	−0.2744	0.4011	0.18	0.10
KU36	0.25	−0.84	8.0	50	44.67	0.2347	0.5857	0.19	0.15
KU37	0.23	−1.42	12.1	56	50..45	−0.2343	0.5943	0.25	0.14
KU38	0.36	−0.87	17.4	50	41.88	−0.4283	0.3872	0.39	0.09
KU39	0.50	−1.87	8.7	36	44.72	3.3814	3.3154	0.18	0.42
KU40	0.30	−0.96	25.8	46	59.71	−0.8345	0.2894	0.39	0.05
KU41	1.01	−0.31	7.4	68	29.05	−2.1717	0.2230	0.15	0.07
KU42	0.32	−4.48	35.4	43	72.75	3.4920	3.5362	0.66	0.34
KU43	1.34	0.53	34.8	56	68.67	−1.3253	0.2749	0.52	0.13
KU44	1.49	0.34	18.0	46	56.02	−2.3510	0.2096	0.37	0.09
KU45	0.61	−0.06	27.7	61	57.06	−2.6284	0.1065	0.45	0.04
KU46	1.17	−0.77	17.7	39	51.10	−1.4983	0.3723	0.39	0.11
KU47	0.63	−0.87	21.1	53	63.96	−0.0681	0.6910	0.33	0.14
KU48	0.74	0.68	16.6	53	59.08	−1.0147	0.4144	0.34	0.07
KU49	0.56	0.72	25.4	57	63.05	−0.6411	0.5103	0.46	0.07
KU50	0.83	−0.16	0.3	43	29.05	−0.5642	0.3867	0.46	0.15

Table 5: Classification of groundwater on the basis of RSC.

RSC (meq·L^{-1})	Quality	Hazards	Samples
<1.25	Good	Low with some removal calcium and magnesium from irrigation water	50 samples
1.25–2.50	Doubtful	Medium with appreciable removal of calcium and magnesium from irrigation water	
>2.50	Unsuitable	High with most calcium and magnesium removed leaving sodium to accumulate	

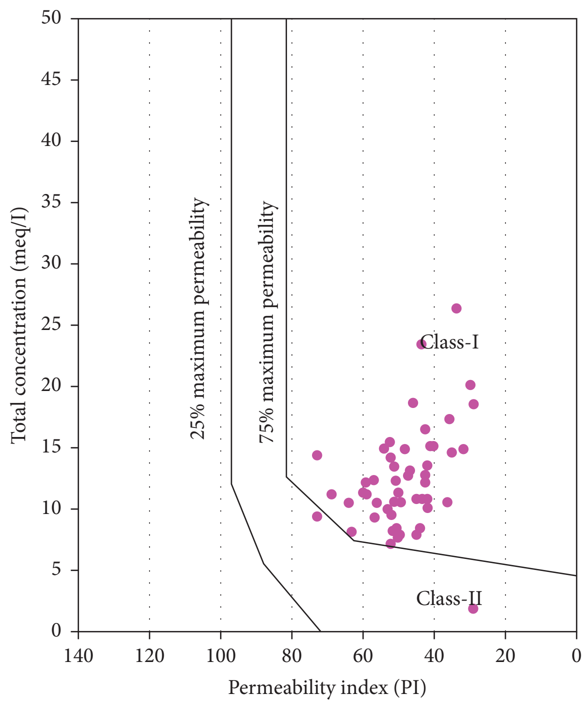


Figure 4: Permeability index diagram classification of groundwater quality.

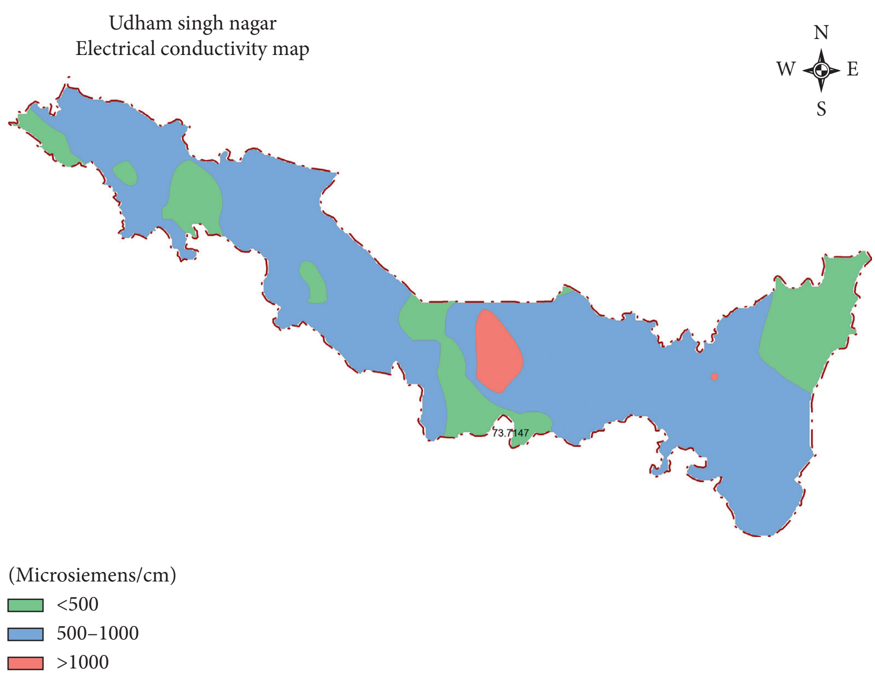


Figure 5: Spatial distribution map of EC.

Almora district [47], MH values of spring water varied from 0.39 to 38.37. Hence, these samples are observed to be unsuitable for irrigation (Table 4).

3.9. Permeability Index (PI). On the basis of PI values, groundwater quality can be assessed for its suitability for irrigation purpose [48]. According to Singh et al., the concentration of Ca^{2+}, Na^{+}, Mg^{2+}, and HCO_3^{-} influences permeability of soil profile [49]. Therefore, these cations and anions are used to calculate PI values of water to evaluate its quality. Xu et al. correlated high PI values with high amount of sodium and bicarbonate ions in groundwater [50]. The high levels of HCO_3^{-} and Na^{+} ions may be due the

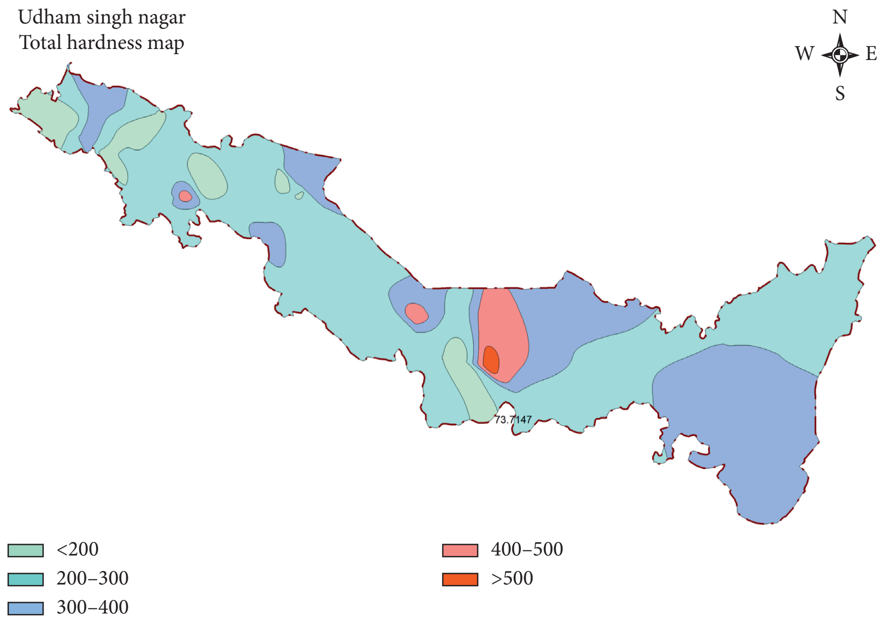


Figure 6: Spatial distribution map of TH.

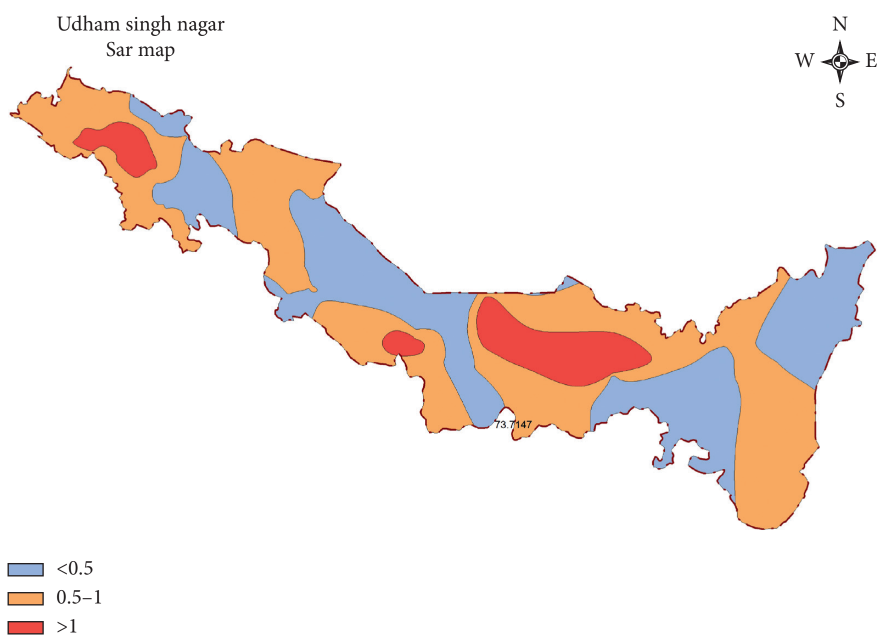


Figure 7: Spatial distribution map of SAR.

dissolution of carbonate from calcite and dolomite and the cation exchange process.

Nagaraju et al. classified water quality on the basis of PI into Classes I, II, and III. Classes I and II indicate good water quality for irrigation purpose (>75% and 25-75% permeability respectively), while Class III (up to 25% permeability) water is unsuitable for irrigation [43]. A high permeability index is associated with subsurface structural features, which facilitate widespread contamination of groundwater. As per the PI values, the groundwater samples of the study area fall in Classes II (29.05-72.75%) and were described as having excellent to good permeability [51] (Table 4 and Figure 4).

3.10. Spatial Distribution Maps. Geographical information system (GIS) is the special tool which is used to create spatial distribution maps, indicating suitable and unsuitable zones based on water quality parameters [52]. In the present study, spatial distribution maps were drawn for EC, TH, SAR, SSP, MH, and PI.

The spatial distribution map of EC is shown in Figure 5. This indicated that more than half of the study area was alkaline in nature. The spatial distribution map of TH suggested that central part of the study area had the high TH value (Figure 6). SAR distribution map indicated that majority of the locations was within the excellent zone (SAR

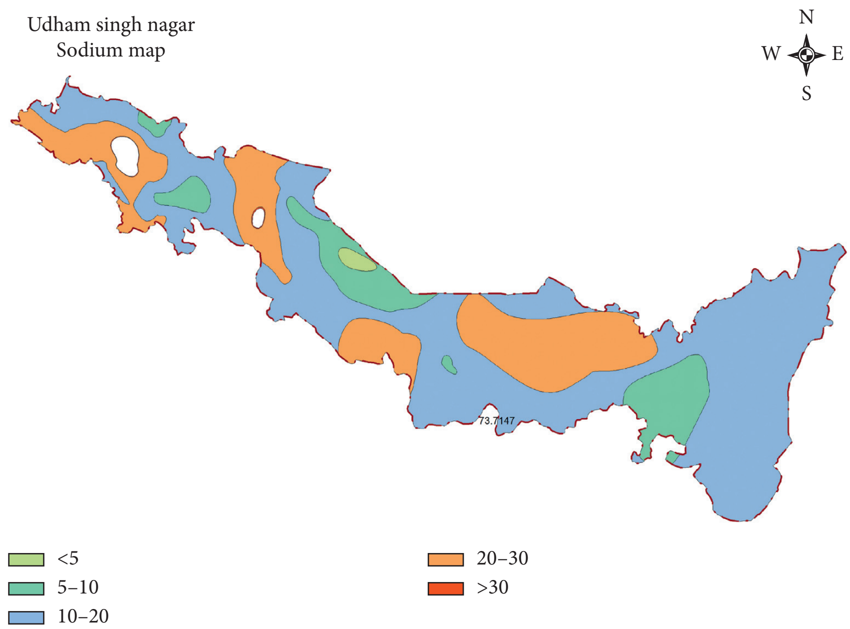


Figure 8: Spatial distribution map of SSP.

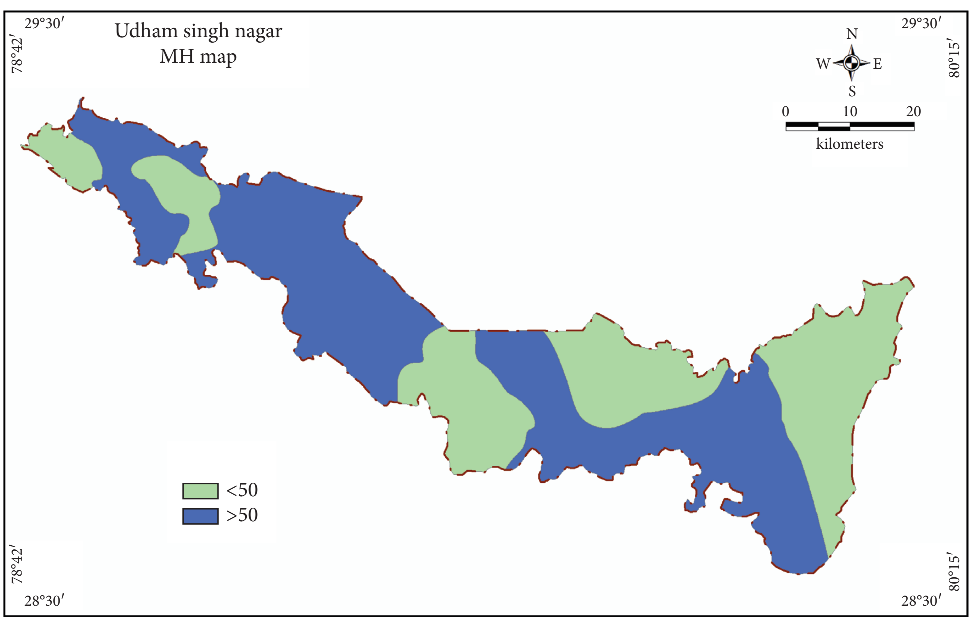


Figure 9: Spatial distribution map of MH.

0.5–1.0) (Figure 7). Figure 8 is the spatial distribution map of SSP. This map suggested that the SSP values of all the samples were excellent to good. The spatial distribution maps indicated that groundwater collected from the central part of the study area was rich in hardness and salinity along with some small patches in the western region. The spatial distribution map of MH is shown in Figure 9, which indicated that the eastern part of the study area is having very low MH values as compared to the western part of the study area. The spatial distribution map indicated that the western region of the study area had the highest PI value. Most of the study area showed permeability index in between 40 and 50% (Figure 10).

3.11. Hydrochemistry

3.11.1. Piper and Durov Diagrams. Hydrochemical interpretation of the analysed samples has been attempted by plotting the data in the Piper and Durov [53] diagrams (Figure 11). In the Piper diagram, analysed chemical data are plotted in two triangular fields, which are ultimately projected into an upper diamond-shaped field. Similar

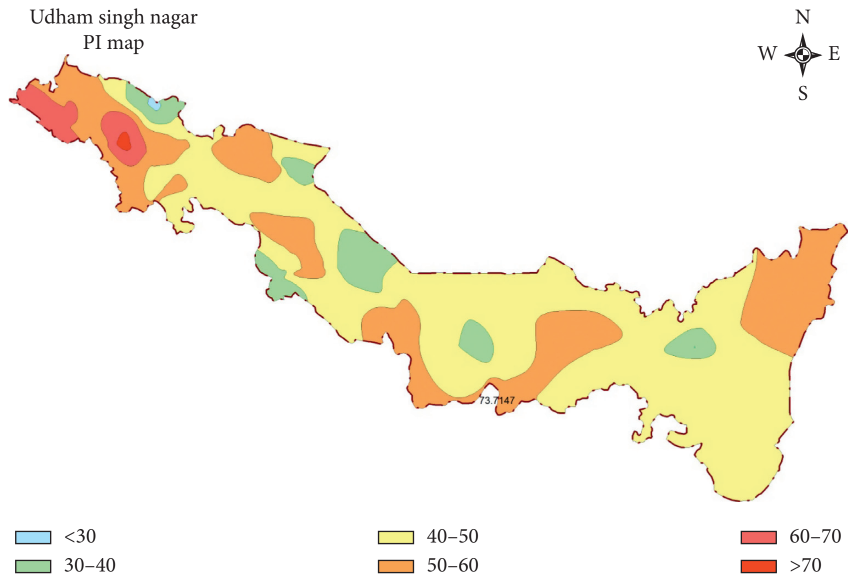
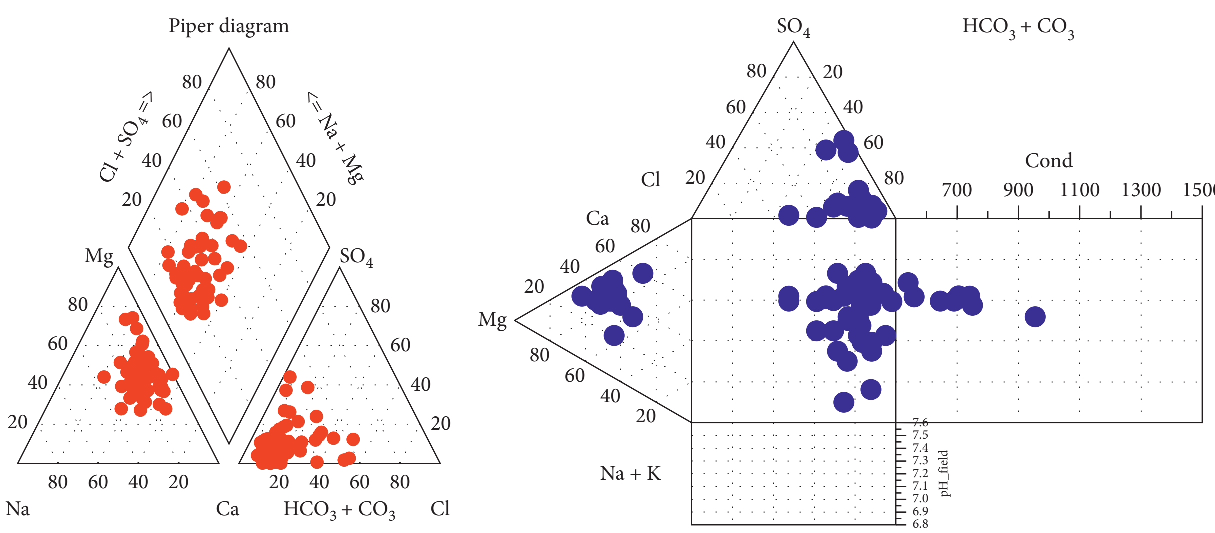


Figure 10: Spatial distribution map of PI.



(a) (b)

Figure 11: Classification of water samples according to (a) Piper and (b) Durov diagrams.

groundwater samples can be identified using this diagram as they are plotted as a cluster. The data plots in the Piper diagram suggested that 50% samples were the Mg^{2+}-Ca^{2+}-HCO_3^- type along with 48% Ca^{2+}–Mg^{2+}-Cl^-type and only two water samples belonged to the Ca-Na-HCO_3 water type. The data plots in Piper diagram and Durov diagram revealed that cations were dominated by Mg^{2+} followed by Ca^{2+} and Na^+, while anions were dominated by HCO_3^-, followed by Cl^- and SO_4^{2-} (Figure 11). The results of the study were similar to the reports on hydrogeochemical analysis of groundwater samples from India [54] and South Africa [55], where they observed that the alkaline earth metals were the dominant metal ions in groundwater samples. High levels of calcium may present naturally, but the dominance of sodium and magnesium ions is due to their dissolution from polluted rocks and soils [56].

3.11.2. Chloroalkaline Index. Scholler observed the change in the chemical composition of groundwater, and its flow can be represented by chloroalkaline indices CAI I and CAI II [28]. Positive value of chloroalkaline index revealed direct ion exchange between Na^+ and K^+ from water and Ca^{2+} and Mg^{2+} with the rocks. When the value of CAI is negative, ion exchange between Mg^{2+} and Ca^{2+} from water and Na^+ and K^+ with rocks happens. The resultant value of CAI I was lying in between −7.7824 and 6.8758 and CAI II −0.0790 and 6.8213 (Table 4). These values indicated that 70% studied

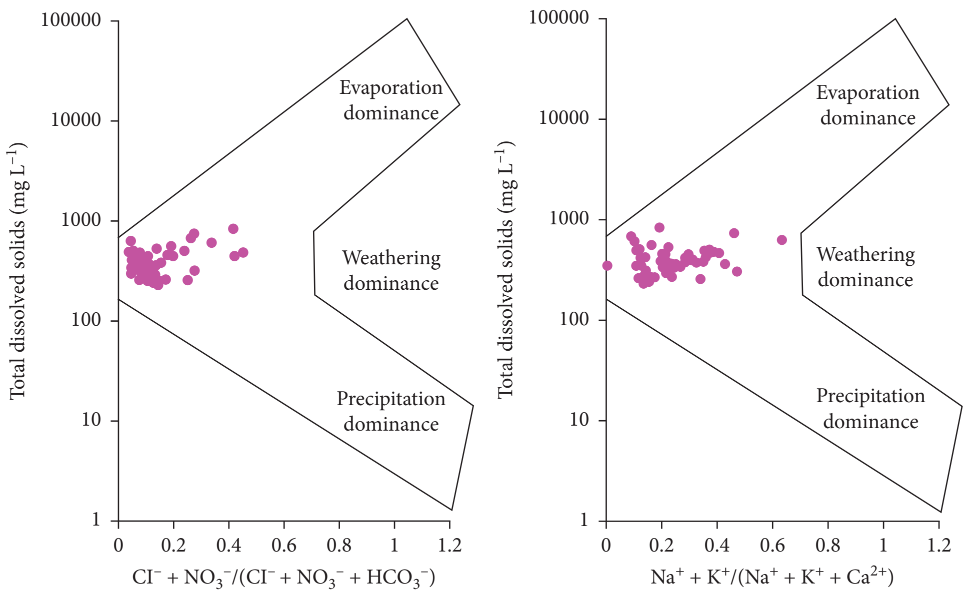


Figure 12: Gibbs diagram for anion and cation against TDS.

area belonged to negative category and 30% felt in the positive zone. Thus, the findings clearly indicated that exchangeable cations can also be used to indicate the chemical composition of groundwater of the study area.

3.11.3. Gibbs Diagram. Gibbs (1970) proposed a diagram for interpretation of the mechanism of major ion chemistry of groundwater samples [57]. The Gibbs diagram explains the three different fields, namely, precipitation dominance, evaporation dominance, and rock dominance. Gibbs ratio was calculated with the help of the following formula:

$$\text{Gibbs ratio 1 (anion)} = \frac{(Cl^- + NO_3^-)}{(Cl^- + NO_3^- + HCO_3^-)},$$
$$\text{Gibbs ratio 2 (cation)} = \frac{(Na^+ + K^+)}{(Na^+ + K^+ + Ca^{2+})}. \quad (7)$$

The concentration of all ions was taken in meq L^{-1}.

Gibbs diagram was plotted in between Gibbs ratio (cation or anion) and total dissolved solid. In the present study area, the value of Gibbs ratio 1 ranged from 0.01 to 0.66 with an average value of 0.33. The value of Gibbs ratio 2 was in between 0.04 and 0.45 with an average value of 0.143 (Table 4). From Figure 12, it can be interpreted that most of the samples belonged to the rock dominance area, representing the influence of the rocks on groundwater aquifer.

4. Conclusions

The groundwater of Udham Singh Nagar district was alkaline and hard to very hard in nature. The values plotted on the USSL diagram suggested that the groundwater samples belonged to C2S1 and C3S1 categories, indicating medium to high salinity and low sodium hazard. The Wilcox diagram suggested that most of the groundwater samples fall in excellent to good category, and some water samples belonged to good category. On the basis of SAR, RSC, SSP, and PI, all the groundwater samples were observed to be suitable for irrigation purpose. Based on the MH values, 54% groundwater samples were found to be unsuitable for irrigation purpose. The most dominated cation was Ca^{2+} followed by Mg^{2+}, Na^+, and K^+, while the order of domination of anions was $HCO_3^- > Cl^- > SO_4^{2-} > NO_3^- > CO_3^{2-}$. Predominance of cations such as magnesium and calcium in the groundwater indicated pollution to anthropogenic activities. All the groundwater samples showed simple mixing of ions as no ion is predominant.

Data Availability

The data (raw process) used to support the finding of this study are included within the research article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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