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Research article

HYDROGEOCHEMICAL ASSESSMENT OF WATER RESOURCES OF BRINGI WATERSHED, KASHMIR HIMALAYAS, INDIA; IMPLICATION ON DRINKING AND IRRIGATION WATER QUALITY

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ABSTRACT: Twenty four water samples from streams and karst springs of Bringi watershed, SE Kashmir were collected on bimonthly basis and analyzed for major ions to assess the water quality for drinking, domestic and agricultural purposes. The Hydrogeochemical assessment revealed that the carbonate weathering as the dominant source of major ions in water samples. The quality assessment was made through the estimation of pH, electrical conductivity (EC), total dissolved solids (TDS), Ca^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, HCO_3^- and SO_4^{2-}. The water samples are suitable for drinking purposes as per WHO and ISI standards. Parameters like magnesium content (MC), percent sodium (PS), total hardness (TH), sodium adsorption ratio (SAR), salinity hazard (SH), potential salinity (PS), salinity index (SI), permeability index (PI) and residual sodium carbonate (RSC) were calculated. Study of all these parameters indicates that the stream and spring water samples are suitable for irrigation purposes.

Key words: Karst springs, Hydrogeochemistry, Water quality, Bringi watershed, Kashmir Himalayas.

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INTRODUCTION

The Bringi watershed (South East Kashmir) is rich in water resources being endowed with glaciers, lakes, network of streams and numerous freshwater karst springs that can meet a variety of water requirements of the area [1]. However, with rapid increase in population and urbanization, the need to meet the increasing demand of drinking, domestic and irrigation consumption, the available water resources are getting depleted and the water quality is getting deteriorated [2,3]. Pure water is considered to have low dissolved or suspended solids and obnoxious gases as well as low biological content. Such high quality of water may be required only for drinking purposes, while for agricultural and industrial purposes, the quality can be quite flexible [4].

Keeping above facts in mind, it becomes imperative to study the hydrogeological regime and groundwater chemistry of the area to obtain the first hand information about the possible geological as well as anthropogenic influence on the water quality in a non – industrial and less human effected area. Assessment of water quality is important to determine its suitability for consumption in drinking, domestic and agricultural sectors.

Study Area

Bringi watershed is one of the main upland catchments of River Jhelum, lies towards South-East of Kashmir Valley, Western Himalayas between latitudes 33°20′ - 33°45′ N and Longitudes 75°10′ - 75°30′ E (Figure 1) and covers an area of 595 Km^2. The elevation of the mountainous catchment ranges from 1650 m (amsl) at Achabal town to more than 4000 m amsl near Sinthan top. The area has a temperate climate with four well developed seasons namely Spring (Mar – May), Summer (Jun – Aug), Autumn (Sep – Nov) and Winter (Dec – Feb). The area receives a mean annual precipitation of 1150 mm, most of which falls during winter and early spring in the form of snow and rain. The mean annual temperature is 12°C.

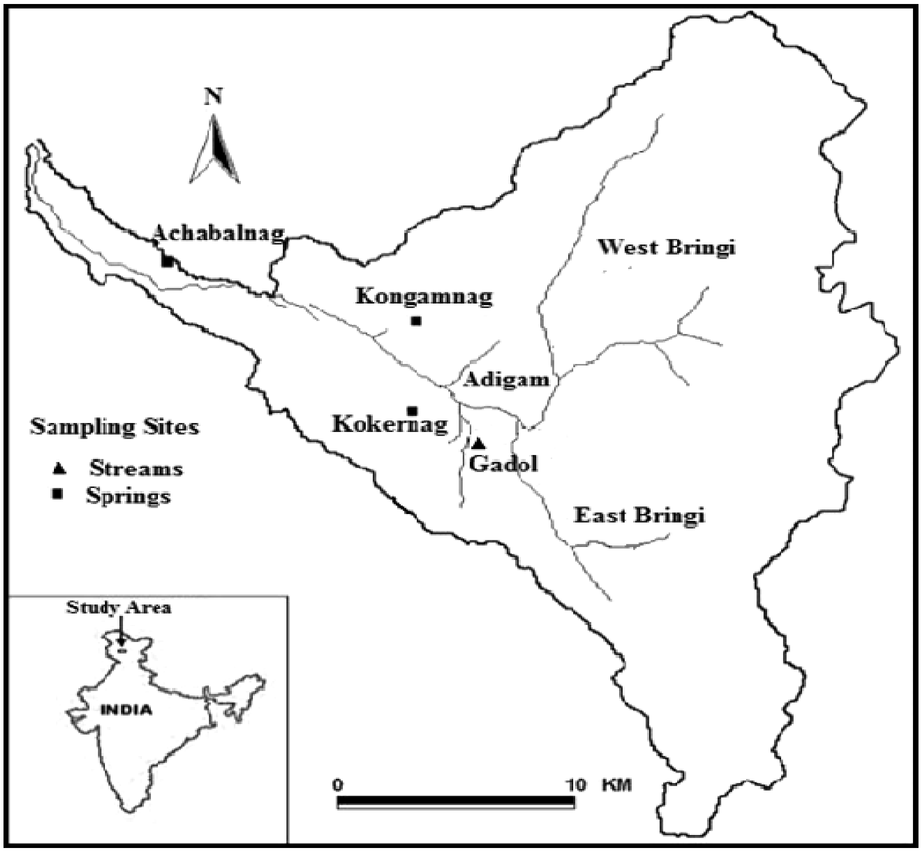

Figure 1: Location map of Bringi watershed showing sampling sites.

The Bringi watershed has a diverse rock types ranging from Paleozoic sedimentary to recent alluvium [5,6,7] with Panjal Traps and Triassic Limestone as the dominant formations of hydrological importance. Groundwater discharge occurs basically through springs hosted by the Triassic Limestone [8]. The most important karst springs are Achabalnag, Kokernag and Kongamnag. The discharge of the first two springs is highly variable and fluctuating. The discharge of Achabal ranges from 160 L/s in winter to about 3,000 L/s in summer and the flow of Kokernag ranges from 600 L/s to about 8000 L/s. Highly fluctuating nature of the discharges and the rapid response of the spring flows to rainfall and snow melting reveals the existence and development of karstic drainage pattern. The average flow of the Kongamnag is about 20 L/s.

METHODOLOGY

Water samples from Bringi stream and the karst springs (Achabalnag, Kokernag, Kongamnag) were collected on bimonthly basis (Figure 1) from March 2008 to January 2009 for major ion study including Ca^{2+}, Mg^{2+}, Na^+, K^+, HCO_3^-, Cl^-, SO_4^{2-}, SiO_2, NO_3^- and F^-. Sample collection, transportation and analysis were done according to the prescribed methods [9]. The bottles caring samples were then labeled and transported to the laboratory for the analysis of other parameters. Stream water samples were collected before the confluence of the stream and spring water samples were collected at the source. The master parameters such as water temperature, pH and electrical conductivity (EC) were determined in situ. Water temperature was measured by the standardized digital temperature meter (EI-421E), pH by the standardized digital pH meter (EI-432) and conductivity by standardized digital EC meter (EI-621). The sampling bottles were then labeled and transported to the laboratory for the analysis of other parameters. For major ion analysis, the samples were filtered through <0.45 Qm nucleopore filter paper to separate the suspended sediments. Major ion analysis was done in the Hydrogeology Laboratory, Department of Earth Sciences, University of Kashmir, Srinagar. Ca^{2+} and Mg^{2+} were determined by EDTA titration using murexide as indicator, whereas the Cl- was determined by titration with $AgNO_3$ (0.02 N) using potassium chromate (5%) as an indicator. The HCO_3^- was determined by the titration of the water sample against HCl (0.01N) in which methyl orange was used as an indicator. The Na^+ and K^+ concentration in the samples were determined by using flame emission photometer (Systronics-130). SO_4^{2-}, SiO_2 and NO_3^- were determined by UV-VIS spectrophotometer (EI-1371).

RESULTS AND DISCUSSION

The analytical data, calculated values, and statistical parameters like mean, maximum, minimum, standard deviations, are given in Table 1. The temperature of the streams corresponds to the ambient temperature, ranging from 9.6°C to 17.4°C, at an average of 12.48°C and that of the springs ranges from 8.2°C to 14.4°C at an average of 12.2°C. Among the springs, Achabalnag and Kokernag show greater annual variability of temperature (~5.4°C and ~3.8°C) compared to Kongamnag with a variability of 1.7°C. The difference in variability in water temperatures may be attributed to shorter route of water at Achabalnag and Kokernag and longer route at Kongamnag. Stream water samples are moderately alkaline to alkaline in nature with pH ranging from 7.8 to 9.8 at an average of 8.2. All the springs of the study area are neutral to moderately alkaline with pH ranging from 7.0 to 8.2 at an average of 7.6. Electric Conductivity of the stream water samples ranges from 140 to 235 µS /cm, at an average of 175 µS /cm. EC of the springs ranges from 142 to 520 µS /cm, with an average value of 314 µS /cm. Highest EC is observed in Kongamnag during March and lowest in Achabalnag during May. Very large variations in the electric conductivity may be attributed to variation to total dissolved solids. The higher EC of the water is result of ion exchange and solubilization in the aquifer system [10]. TDS in the stream water samples vary from 89 to 193 mg/l with a mean of 122 mg/l. TDS in the spring water samples ranges from 90 to 339.2 mg/l, with a mean of 206 mg/l. Highest concentration of TDS is observed in Kongamnag during March and lowest concentration is observed in Achabalnag during May. However, like EC, Achabalnag and Kokernag also show increased TDS during July. During winter season, because of frost action and less groundwater recharge, there is more residence time of groundwater which has resulted in prolonged rock–water interaction and thus more ions are acquired [3]. On the other hand, during summer there is significant groundwater recharge and less residence time of groundwater which has resulted in low rock–water interaction, which lowers the dissolved ions in springs. At Achabalnag and Kokernag, the ions also show high concentration during July which may have resulted from the piston effect [3]. Both stream and spring water samples falls under fresh (TDS<1000 mg/l) types of water [11].

Table 1: Analytical data, calculated values and statistical parameters of water samples of study area.

Sample Type	Sampling Date & No.	Statistics	Temp. (°C)	pH	EC	TDS	SiO_2	F	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-
					µS/cm	mg/L						meq/L				
Streams	Mar to Jan, N=6	Min.	9	7.8	140	89	0.2	0.8	0.35	0.59	0.08	0.10	0.0003	0.66	0.06	0.01
		Max.	17.4	9.8	235	150.4	1.7	1.4	4.2	1.62	0.81	0.31	0.0051	2.13	0.32	0.16
		Mean	12.4	8.3	174.7	110.7	1.2	1.0	1.61	0.86	0.30	0.18	0.0029	1.12	0.15	0.06
		St. Dev	3.3	0.8	38.2	25.4	0.5	0.3	1.53	0.38	0.26	0.08	0.0020	0.54	0.10	0.05
Springs	March, N=3	Min.	10.9	7.1	200	128	1.04	0.83	0.65	1.03	0.36	0.09	0.0003	1.15	0.16	0.09
		Max.	13.1	7.6	530	339.2	1.6	0.9	3.18	1.93	1.62	0.57	0.0005	3.61	0.38	0.19
		Mean	11.7	7.3	314.0	201.0	1.3	0.85	2.0	1.39	0.82	0.30	0.0004	1.97	0.29	0.15
		St. Dev	1.2	0.3	187.2	119.8	0.3	0.04	1.27	0.48	0.69	0.25	0.0001	1.42	0.11	0.05
	May, N=3	Min.	11.2	7.4	142	90.88	0.5	0.82	1.25	0.48	0.32	0.10	0.0018	0.74	0.24	0.07
		Max.	13	8	442	282.8	0.7	0.86	4.2	1.84	0.97	0.52	0.0028	2.79	0.26	0.17
		Mean	12.2	7.7	243.3	155.7	0.6	0.84	2.9	0.99	0.55	0.26	0.0022	1.42	0.25	0.11
		St. Dev	0.9	0.3	172.1	110.1	0.1	0.02	1.5	0.74	0.36	0.23	0.0005	1.18	0.01	0.05
	July, N=3	Min.	10.4	7.2	236.0	151.0	0.5	0.82	1.2	1.11	0.32	0.09	0.0010	1.56	0.24	0.01
		Max.	14.3	7.8	454.0	290.6	0.75	1.25	4.55	1.85	1.54	0.58	0.0033	3.03	0.70	0.10
		Mean	12.8	7.4	338.7	216.7	0.6	1.09	3.06	1.49	0.77	0.27	0.0019	2.24	0.43	0.04
		St. Dev	2.1	0.3	109.6	70.1	0.15	0.23	1.7	0.37	0.67	0.27	0.0013	0.74	0.24	0.05
	September, N=3	Min.	12.0	7.0	222.6	142.5	0.7	0.62	0.85	1.27	0.49	0.11	0.0036	1.48	0.07	0.02
		Max.	14.4	7.7	448.0	286.7	1.9	0.72	5.75	1.62	1.42	0.65	0.0054	3.20	0.75	0.24
		Mean	13.4	7.3	319.7	204.6	1.2	0.65	3.4	1.42	0.82	0.32	0.0047	2.13	0.37	0.10
		St. Dev	1.2	0.4	115.9	74.2	0.6	0.05	2.45	0.18	0.52	0.29	0.0010	0.93	0.35	0.12
	November, N=3	Min.	11.9	7.3	212.2	135.8	0.6	0.74	0.72	0.68	0.73	0.13	0.0026	1.23	0.20	0.04
		Max.	14.3	8.1	454.8	291.1	1.7	0.96	5.0	1.73	1.46	0.24	0.0054	3.44	0.55	0.22
		Mean	13.3	7.6	305.7	195.7	1.0	0.85	3.34	1.14	1.01	0.19	0.0041	2.02	0.38	0.11
		St. Dev	1.2	0.4	130.5	83.5	0.6	0.11	2.29	0.54	0.39	0.06	0.0014	1.23	0.17	0.10
	January, N=3	Min.	8.2	7.6	280.2	179.3	0.17	0.86	0.68	1.62	0.69	0.11	0.0041	1.97	0.06	0.00
		Max.	12.0	8.2	520.2	332.9	1.7	0.96	4.2	2.33	1.70	0.23	0.0062	3.93	0.18	0.19
		Mean	9.7	7.9	367.5	235.2	0.7	0.9	2.89	1.86	1.07	0.17	0.0051	2.68	0.12	0.07
		St. Dev	2.0	0.3	132.7	84.9	0.9	0.05	1.92	0.40	0.55	0.06	0.0010	1.09	0.06	0.10

Major Ion Chemistry

Major cation chemistry of the water samples is dominated by Ca followed by Mg, Na and K and among the anions, the dominant ions include HCO_3 followed by SO_4, Cl and NO_3. As the area is dominantly a karst terrain, calcium and magnesium ions may be derived from leaching of limestone, dolomites, gypsum and anhydrites (Eq. 1). The calcium ions can also be derived from cation exchange process [12].

$(Ca, Mg)\,CO_3+CO^2+H_2O=2HCO^-_3+Ca^{2+}+Mg^{2+}$ (1)

The (Ca+Mg) vs. (HCO_3+SO_4) scatter diagram [13] (Figure 2A) shows that majority of the samples fall above the equiline indicating that the carbonate weathering is the dominant process for supply of the calcium and magnesium ions to the groundwater. The possible source of sodium concentration in groundwater is due to dissolution and weathering of sodium bearing minerals. If the halite dissolution process is responsible for the sodium concentration in the ground water, Na/Cl ratio should be approximately 1, whereas the Na/Cl ratio greater than 1 typically indicates that the sodium was released from silicate weathering [14]. In the study area, the majority of the samples show Na/Cl ratio greater than 1 indicating that the silicate weathering is the dominant process for the release of sodium in the groundwater (Figure 2B). Potassium ion concentration in the groundwater also comes from the above said process. The carbonate and bicarbonate concentration in groundwater is derived from carbonate weathering as well as dissolution of carbonic acid in the aquifers (eq. 2) [15].

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{2+} + 2HCO_3^- \text{ and } CO_2 + H_2O \rightarrow H^+ + HCO_3^- \qquad (2)$$

Like Ca and Mg, the bicarbonate ion concentration in the water samples may be attributed to the carbonate weathering in the study area [3] and/or availability of the carbonate minerals in the recharge area [16]. The natural process such as weathering, dissolution of salt deposits, and irrigation drainage return flow are responsible for chloride content in the groundwater, which is supported by Cl/HCO_3 ratio of 0.01 to 0.17 [17]. Sulfate ion concentrations are derived from weathering of sulfate and gypsum-bearing sedimentary rocks [15,16]. The sources of nitrate content in the groundwater of the study may be credited to the irrigation return flow as lot of fertilizers are used in the agricultural fields in and around the study area.

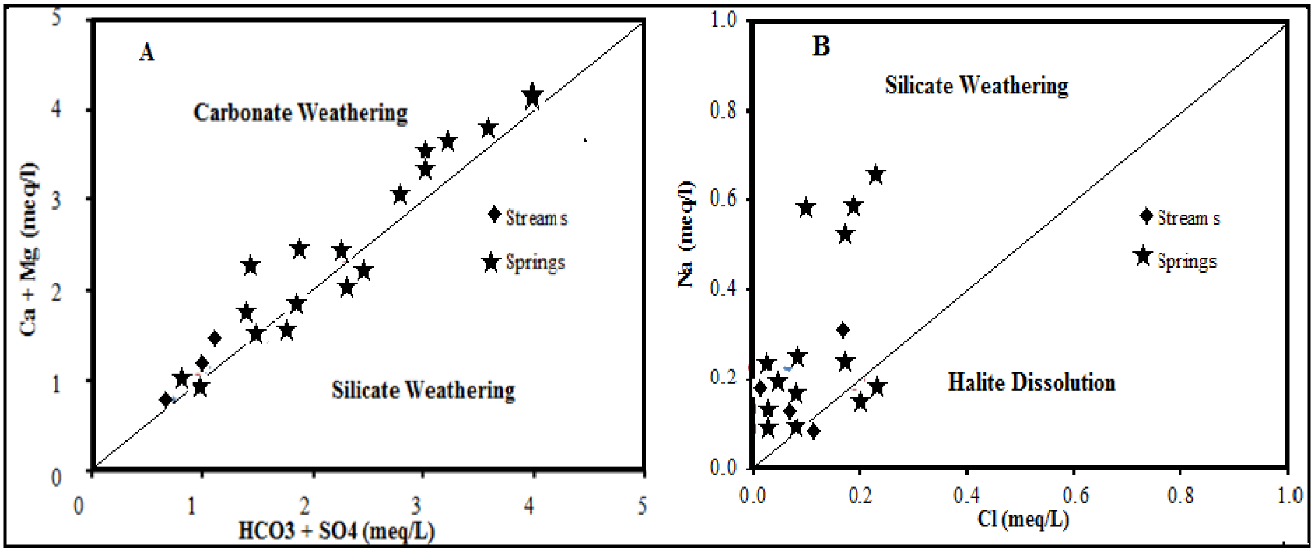

Figure 2 (A): (Ca + Mg) vs. (HCO_3 + SO_4) Plot (After Dutta & Tyagi) and 2 (B) Showing Na Vs Cl Plot (after Meyback).

Quality Evaluation

The water quality evaluation in the water samples of the study area is carried out to determine the portability in terms of drinking, domestic and agricultural purposes. This is based on standards prescribed by WHO and ISI, TDS classification, hardness, salinity and alkali hazard (Sodium adsorption ratio, SAR vs. conductivity).

Water Quality for drinking purposes

The major ions in the water samples are well below standards prescribed by [18] and [19] for drinking purposes (Table 2). However, there is an increase in concentration of major ions particularly nitrates and chlorides, which are mainly due to agricultural and domestic waste disposals. The high concentration of chemical species is mainly observed during spring season, may be due to flushing of sanitary waste disposal sites and surrounding soils in settlements without sewage and waste water treatment.

Table 2: Compliance of surface and groundwater quality of water samples (%) to drinking standards.

Chemical Constituents	WHO (1984)	ISI (1983)	Samples (%) exceed safety limits
pH	7-8.5	7-8.5	4
TDS	500	500	Within the range
TH	100	300	42
Ca^{2+}	75	75	Within the range
Mg^{2+}	30	30	Within the range
Na^+	200	-	Within the range
K^+	12	-	Within the range
HCO_3^-	-	300	Within the range
SO_4^{2-}	200	150	Within the range
Cl^-	200	250	Within the range
NO_3^-	45	45	Within the range
F^-	1.5	0.6-1.2	Within the range

Based on total dissolved solids, the water of both the streams and springs are classified into desirable for drinking (up to 500 mg/l), permissible for drinking (500–1,000 mg/l), useful for agricultural purposes (up to 3,000 mg/l) [20]. The samples of the study area fall in the desirable to permissible category for drinking purposes and all the samples are fit for agricultural uses according to the mentioned criteria (Table 3). As per the classification of TDS [21], all the water samples come under fresh water type (TDS < 1000 mg/L)

Table 3: Water Quality for Drinking and agricultural purposes (After Davis and De Wiest).

TDS mg/l	Remarks on Quality	No. of Samples	%age of Samples
Up to 500	Desirable for Drinking	24	100
500-1000	Permissible for Drinking	----	----
Up to 3000	Useful for Agricultural	----	----
>3000	Unfit for Drinking and Irrigation	----	----

Water Quality for Agriculture

Irrigated agriculture depends upon the adequate water supply of usable quality. Emphasis is placed on the physical and chemical characteristics of water in irrigation water quality evaluation. The quality characteristics in present investigation include Electrical Conductivity (EC), Total Dissolved Solids (TDS), Magnesium Content (MC), Percent Sodium (PS), Total Hardness (TH), Sodium Adsorption Ratio (SAR), Salinity Hazard (SH), Potential Salinity (PS), Salinity Index (SI), Permeability Index (PI) ans Residual Sodium Carbonate (RSC).

Electrical Conductivity (EC)

The most influential water quality parameter on crop productivity is the water salinity hazard as measured by Electrical Conductivity (EC). The primary effect of high EC on crop productivity is the inability of plants to compete for water with ions in soil solution. Higher the EC, less water is available to plants. Water with EC less than 250 µS/cm is considered good and EC more than 750 µS/cm is unsuitable for irrigation. The EC of stream water samples ranged between 140 to 235 µS/cm, are good for irrigation purposes. The EC of spring water samples ranged between EC of the springs ranges from 142 to 520 µS/cm, with an average value of 314 µS /cm.

Total Dissolved Solids (TDS)

The type and quantity of dissolved salts in water determine the quality of water for irrigation purposes. The salts originate from weathering and dissolution of rocks and soils including lime, gypsum and other soil minerals. A salinity problem exists if the dissolved salts accumulate in the root zone of crops to a concentration that causes a loss in yield. Water with TDS less than 450 mg/l is considered good and concentration more than 2000 mg/l is unsuitable for agriculture. The TDS of stream and spring water samples of the study area is below 450 mg/l and are good for irrigation purpose.

Magnesium Content

Magnesium content of water is considered as one of the most important qualitative parameter in determining the quality of water for irrigation. Magnesium content is calculated by the following formula.

$$\text{Mg content} = \{Mg^{2+} / (Mg^{2+} + Ca^{2+})\}\ 100 \qquad (3)$$

Where, all the ions are reported in milliequilents. Generally, Calcium and Magnesium maintains a state of equilibrium in most waters. However, excess magnesium will adversely affect crop yield as the soils become more alkaline. The magnesium content in water samples of study area range between 0.48 meq/l to 3.26 meq/l and are suitable for irrigation purposes.

Percent Sodium (Na %)

Sodium percent is another important parameter to study the sodium hazard. Higher concentration of sodium in irrigation water leads to its adsorption by clay particles, displacing magnesium and calcium ions. This exchange process of sodium reduces the permeability of the soil and eventually results in poor internal drainage of the soil. Hence, air and water circulation is restricted during wet conditions and such soils are usually hard when dry [22, 23]. Several methods have been used to classify and understand the basic character of the chemical composition of groundwater [24,25], since the suitability of the groundwater for irrigation depends on the mineralization of water and its effect on plants and soil. Percent sodium is calculated by the following equation [26]

$$Na\% = \{(Na^{+} + K^{+})/ (Ca^{2+} + Mg^{2+} + Na^{+} + K^{+})\}\ 100 \qquad (4)$$

Where, all ions are reported in milliequilents. The classification of water samples with respect to percent sodium is shown in Table 4 and it is found that 95.87 % of the samples fall in the excellent category, 4.17% of the samples fall in the good category, showing that majority of the samples in the study area is suitable for irrigating the most types of soils. Based on percent sodium, irrigation water has been classified into two categories with percent sodium greater than sixty percent as unsafe and the water with percent sodium less than sixty as safe [27]. Accordingly the 100% of the samples from the study area fall in the safe category.

Table 4: Water Classes Based on Percent Sodium (After Wilcox).

% Sodium	Water Class	No. of samples	% age of samples
<20	Excellent	23	95.83
20-40	Good	1	4.17
40-60	Permissible	---	---
60 - 80	Doubtful	---	---
>80	Unsuitable	---	---

Table 5: Hardness Classes of water (After Sawyer and McCarthy).

TH as $CaCO_3$ (mg/l)	Water Classes	No. of samples	%age of Samples
<75	Soft	9	45
75 - 150	Moderately Hard	10	41.6
150-300	Hard	5	20.8
>300	Very hard	----	----

Wilcox diagram with %Na plotted against specific conductance is used in evaluating irrigation waters [24]. An appraisal of the Wilcox diagram (Figure 3) shows that most of the samples from the study area fall under excellent to permissible fields of the diagram indicating that water samples from the study area are suitable for the irrigation purposes for majority of crops and most of the soils.

Total hardness

Hardness of the water has no known adverse effects; however, it causes more consumption of detergents at the time of cleaning, and some evidence indicates its role in heart disease [28]. The total hardness (TH) in ppm [29, 30, 31] determined by Eq. 5:

$$TH = 2.497\ Ca^{2+} + 4.115\ Mg^{2+} \ (5)$$

The classification of the water samples of the study area based on hardness [32] is presented in Table 6. Accordingly the water samples of the study area are soft to hard with 45% of samples falling in soft category, 41`.6 % in moderately hard and 20.8% falling in very hard category.

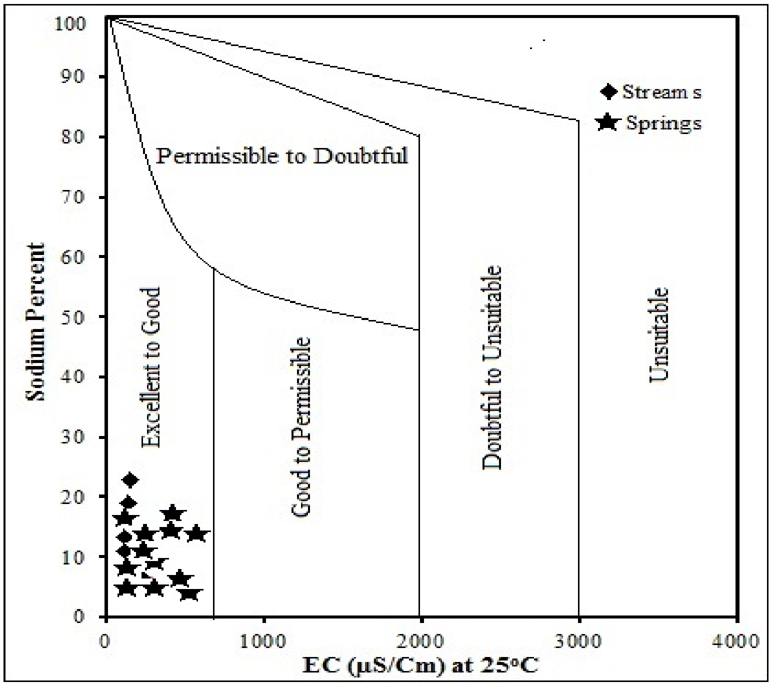

Figure 3: Wilcox Diagram showing suitability of water for irrigation (After Wilcox).

Table 6: Waters classes based on SAR values (Todd, Richards) and sodium hazard classes based on USSL classification.

SAR	Sodium hazard class	Remarks on Quality	No. of Samples	% age of samples
<10	S1	Excellent	24	100%
10-18	S2	Good	----	---
19-26	S3	Doubtful/ Fair/ Poor	----	---
>26	S4 and S5	Unsuitable	----	---

Sodium adsorption ratio (SAR)

High concentration of sodium in water produces undesirable effects of changing soil properties and reducing soil permeability [33] and thus reduces the supply of water needed for the crops. The SAR measures the relative proportion of sodium ions to those of calcium and magnesium in water. SAR is used to predict the sodium hazard of high carbonate waters especially if they contain no residual alkali. The excess sodium or limited calcium and magnesium content are evaluated by SAR [34], computed as:

$$SAR = Na^+ / \surd \{(Ca^{2+} + Mg^{2+}) / 2\} \qquad (6)$$

The classification of groundwater samples from the study area with respect to SAR [25,31] is presented in Table 7. The SAR value in the study area ranges from 0.1 to 0.53 with mean value of 0.24 which means that all the samples from the study area are classified as excellent for irrigation as all the samples fall in S1 category (sodium hazard class).

Table 7: Salinity Hazard classes (After Richards).

Salinity Hazard Class	EC (µS/cm)	Remarks on Quality	No. of Samples	% age of Samples
C1	100- 250	Excellent	15	62.5
C2	250-750	Good	9	37.5
C3	750-2250	Doubtful	----	----
C4 and C5	>2250	Unsuitable	----	-----

Salinity hazard

The total concentration of soluble salts (salinity hazard) in irrigation water can be expressed in terms of specific conductance. Classification of groundwater based on salinity hazard is presented in Table 8. It is found from the salinity hazard classes that 62.5% of the samples fall in the excellent category and 37.5% samples fall in good category for irrigation purposes. Groundwater samples that fall in the low salinity hazard class (C1) can be used for irrigation of most crops and majority of soils. However, some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability. Groundwater samples that fall in the medium salinity hazard class (C2) can be used if a moderate amount of leaching occurs. High salinity (C4 and C5) can be suitable for plants having good salt tolerance but restricts its suitability for irrigation, especially in soils with restricted drainage [33, 35]. High salinity water (C3, C4, and C5) cannot be used in soils with restricted drainage. Even with adequate drainage, special management for salinity control is required, and crops with good salt tolerance should be selected. Such areas need special attention as far as irrigation is concerned. A more detailed analysis for the suitability of water for irrigation can be made by plotting the sodium absorption ratio and electrical conductivity (Figure 4) data on the US Salinity Laboratory (USSL) diagram [31]. Accordingly, 15 samples fall in the category of C1S1 (62.5%), indicating a low salinity/low sodium type and the remaining 9 samples (37.5%), belong to C2S1 category.

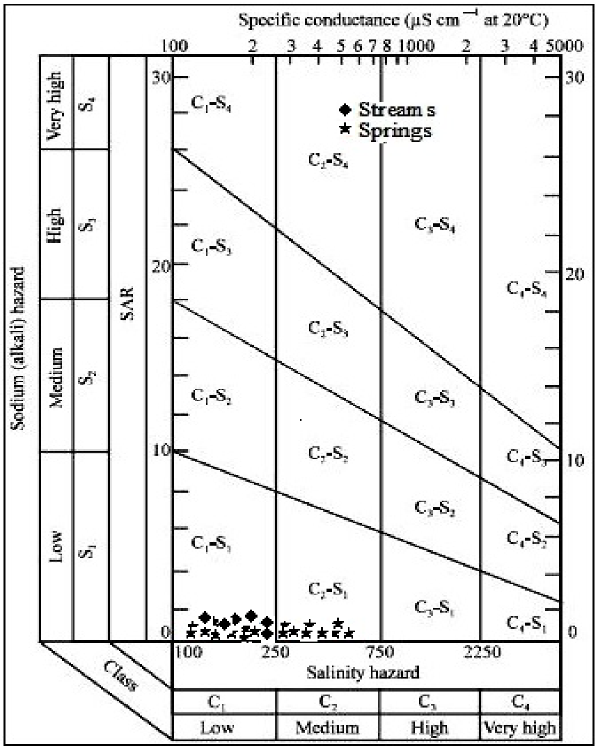

Figure 4: USSL Salinity Hazard Diagram (after Richards) depicting classification of water for irrigation.

Table 8: Salinity Hazard classes (After Handa).

EC (µS/cm)	Water salinity	No. of Samples	% age of Samples
0–250 Low	Low (excellent quality)	15	62.5
251–750	Medium (good quality)	9	37.5
751–2,250	High (permissible quality)	---	----
2,251–6,000	Very high	----	----
6,001–10,000	Extensively high	----	----
10,001–20,000	Brines weak concentration	----	----
20,001–50,000	Brines moderate concentration	----	----
50,001–100,000	Brines high concentration	----	----
>100,000	Brines Extremely high concentration	----	----

Potential salinity

The suitability of water for irrigation is not dependent on the concentration of soluble salts in the water [36,37]. However, low solubility salts precipitate in the soil and accumulate with each successive irrigation, whereas the concentration of highly soluble salts increases the salinity of the soil [26]. An important parameter "Potential salinity" was introduced for assessing the suitability of water for irrigation uses which may be defined as the chloride concentration plus half of the sulfate concentration [26].

$$\text{Potential Salinity} = Cl + \tfrac{1}{2}\, SO_4 \quad (7)$$

It is generally found that PS values are more pronounced in the estuarine region than in the fresh water region samples and is expressed in milliequivalents per liter. The huge amount of potential salinity in the estuarine region is due to the presence of chlorides, which are derived from sea source. The potential salinity of the water samples in the study area varied from 0.03 meq/l to 0.39 meq/l at an average value of 0.22 meq/l. It shows that the potential salinity in the water samples of the study area is low, thus, making the water useful for irrigation purposes.

Salinity index

The salinity index of the groundwater samples was computed using the measured electrical conductivity values (Table 8). On the bases of salinity index classification of water samples [38], all the samples fall under low to medium salinity classes. The majority of the samples (62.5%) belong to the low salinity category and 37.5% belong to medium salinity category, indicating that the water is of good to excellent quality for irrigation. Water exhibiting low to medium salinity (classes 1 and 2) are considered very good to soils or crops, whereas those exhibiting high salinity (class 3) are suitable for irrigating the medium and high salt-tolerant crops. High salinity water (class 4) is suitable for irrigating high salt-tolerant crops, whereas water of salinity class 5 or above is generally unsuitable for irrigation. All of the groundwater samples in the study region are categorized as classes 1–2 and thus may be considered as suitable for irritation.

Permeability Index

The permeability of the soil is affected by the long term use of water influenced by Na^+, Ca^{2+}, Mg^{2+}, and $HCO_3^{-.}$ Several criterions have been evolved for assessing the suitability of water for irrigation [25, 36] based on permeability index (P.I.). The permeability index can be calculated as given as:

$$PI = Na + \sqrt{HCO} / (Ca + Mg + Na) \qquad (8)$$

Where, all the ions are reported in milliequilents. As per the Doneen's chart waters can are classified as Class I, Class II, and Class III. Class I and Class II represent waters which are good for irrigation with 50–75% or more of maximum permeability. Class III waters are unsuitable with 25% of maximum permeability. An appraisal of the Figure 5 shows that all the samples from the study area fall in class I field of the Doneen's Chart showing that maximum permeability is more than 75% which indicates that the water is excellent for the irrigation purposes.

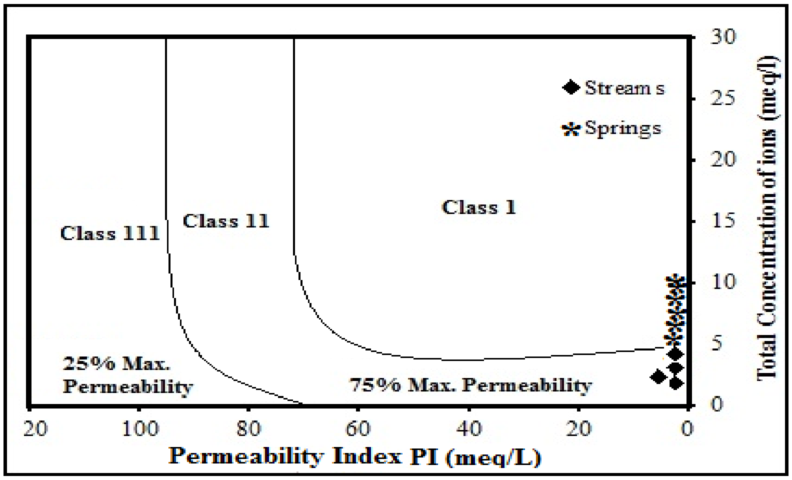

Figure 5: Doneen's Chart of Permeability Index (After Doneen).

Residual sodium carbonate

When concentration of carbonates and bicarbonates exceeds that of calcium and magnesium, there may be possibility of complete precipitation of calcium and magnesium [39]. Bicarbonate and carbonate is considered to be detrimental to the physical properties of soils, as it causes dissolution of organic matter in the soil, which in turn leaves a black stain on the soil surface on drying. As a result, the relative proportion of sodium in the water is increased in the form of sodium carbonate, and this excess, denoted by RSC, is calculated as given below [27, 36].

$$RSC = (HCO_3^- + CO_3) - (Ca^{2+} + Mg^{2+}) \quad (9)$$

According to the US Department of Agriculture, water having more than 2.50 epm of RSC is not suitable for irrigation purposes. A high value of RSC in water leads to an increase in the adsorption of sodium in soil (Eaton, 1950). The groundwater in the study area is classified on the basis of RSC [31]. Accordingly, 100% of samples fall in the suitable category.

CONCLUSION

The groundwater in the study area is slightly acidic to slightly alkaline, and belongs to soft to hard with 45% of samples falling in soft category, 41`.6 % in moderately hard and 20.8% falling in very hard category. As per the classification of TDS all the water samples come under fresh water type (TDS < 1000 mg/L) and are desirable both for drinking and agricultural purposes. Chemical analysis of the water samples revealed that Ca^{2+} was the dominant cation followed by Mg^{2+}, Na^+ and K^+. Among the anions, HCO–3 was the most dominant followed by SO_2^{4-}, Cl^- and NO_3. The order of four hydrochemical water types identified was $Ca–Mg–HCO_3 > CaCO_3 > Ca–Mg–Na–HCO_3 > Ca–Na–HCO_3$ it suggests congruent dissolution of carbonate-hosted lithology. The suitability of groundwater for irrigation was evaluated based on the irrigation quality parameters like electrical conductivity, total dissolved solids, magnesium content, percent sodium, total hardness, sodium adsorption ratio, salinity hazard, potential salinity, salinity index, permeability index and residual sodium carbonate. According to the values of these parameters the groundwater of the study area was found suitable for irrigation. It may be concluded that all the parameters show that almost all samples can be used for irrigating most of the crops and soils.

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