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An evaluation of groundwater quality within Srinagar district, Jammu and Kashmir

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ABSTRACT

The objective of this study was to assess the physicochemical characteristics and overall quality of groundwater and its suitability for both drinking and irrigation. Thirty-five groundwater samples were collected from wells and analyzed for key parameters, including pH, electrical conductivity (EC), total dissolved solids (TDS), total alkalinity (TA), total hardness (TH), and major ions (Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, HCO_3^{-}, Cl^{-}, SO_4^{2-}, and Fe). The results revealed slightly alkaline pH levels while EC and TDS levels indicated slight salinity, with Handa's classification showing suitability for domestic and agricultural use despite over 50% of samples having medium salinity and the rest exhibiting high but permissible salinity levels. The water is predominantly hard to very hard, with calcium and bicarbonate as the dominant ions, reflecting the influence of carbonate weathering. Statistical and geochemical analyses, including Piper and Gibbs diagrams, confirm that rock weathering is the primary factor governing groundwater chemistry, with minimal anthropogenic impact reveal that most samples are suitable for irrigation, though localized areas with higher salinity require careful management. The Water Quality Index (WQI) value of 27.70 classifies the water as good for domestic consumption, and most samples meet WHO and BIS standards except for elevated iron levels in several sites, which require treatment to ensure safe consumption. This study highlights the need for continuous monitoring and localized mitigation strategies to address issues like high salinity, hardness, and iron concentrations, ensuring the region's sustainable use of groundwater resources.

KEYWORDS

Groundwater; Srinagar; Salinity hazard; Sodium hazard; WQI; Irrigation; Carbonate weathering

ARTICLE HISTORY

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Introduction

Groundwater, an indispensable resource serving domestic, industrial, and agricultural needs, plays a pivotal role in the global water cycle. Yet, its quality is perpetually at risk due to the dual pressures of anthropogenic activities and natural processes that introduce various contaminants into aquifer systems. The composition and quality of groundwater are governed by a complex interplay of hydrological, physical, chemical, and biological factors. The chemistry of groundwater, in particular, is highly susceptible to an array of influences, including the underlying regional geology, the extent of chemical weathering affecting rock formations, the quality and characteristics of recharge water, and the myriad subsurface geochemical reactions. These variables collectively determine the physicochemical properties of groundwater, shaping its suitability for various uses and highlighting the intricate balance required for its sustainable management [1-4]. The hydrochemical characteristics of groundwater are crucial in deciding whether it is suitable for industrial, agricultural, and drinking uses. Arid and semi-arid regions, facing limited surface water resources, are particularly vulnerable to groundwater quality issues due to their heavy reliance on this resource for their water needs. In these settings, poor water quality can severely restrict access to potable water and compromise agricultural productivity. Consequently, understanding the natural hydrochemical evolution of groundwater is essential for sustainable water resource management [5]. Several hydrogeologic factors shape the chemical composition of groundwater, including mineral weathering, topographic relief, rainfall patterns, and biological activity within the recharge basin [6]. These processes influence how water infiltrates and interacts with soil and rock layers, driving hydrogeochemical reactions that impact the groundwater's overall chemistry. Key factors such as precipitation composition, geological structures, aquifer mineralogy, and hydrological processes determine the quality and variability of groundwater [7]. The chemistry of groundwater is especially sensitive to interactions between water and the host rocks, which can alter its composition over

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time [8]. In addition to natural processes, groundwater quality is increasingly threatened by anthropogenic factors. A range of pollutants, originating from both identifiable sources (point sources) and diffuse sources (non-point sources), degrade water quality. These pollutants include agricultural runoff, industrial and animal waste, household chemicals, and effluent from failing septic systems [9-14]. These pollutants can pose serious risks to human health, aquatic ecosystems, and crop production if not adequately managed. Although the Kashmir Valley is endowed with numerous freshwater sources like lakes, rivers, and springs, providing adequate water for residential and farming purposes has become progressively more problematic. Upland areas like the Karewas and urban centres experience water scarcity, especially during the dry late-summer months when surface water supplies become insufficient and unreliable. This has led to frequent water crises in the region. In the Srinagar district, groundwater has become the primary water source for various needs due to the scarcity of clean and safe surface water options. This preference for groundwater is largely attributed to the limited availability of surface water sources that meet the necessary standards for purity and potability, making groundwater a more reliable and accessible alternative for the local population. Furthermore, groundwater is often a preferred source due to the natural filtration provided by soil and rock formations. This natural process enhances water quality, making it a safer option for both human consumption and agricultural practices [15]. Consequently, the effective management of groundwater resources is not only essential but also critical to ensuring the long-term sustainability of water supplies for the region's expanding population and its increasing agricultural demands. This responsible stewardship safeguards this vital resource for future generations and maintains the delicate balance of the region's ecosystem.

Study Area

Srinagar district, a cultural and historical heart of the Kashmir Valley, is strategically positioned between latitudes 34°3'N and 34°20'N, and longitudes 74°40'E and 75°15'E, as illustrated in Figure 1. Encompassing an area of approximately 2,228 square kilometres, the district is renowned for its picturesque landscapes, characterized by verdant meadows, serene lakes, and meandering rivers. As the summer capital of Jammu and Kashmir, Srinagar is nestled amidst the majestic Himalayan Mountains. Its temperate climate, marked by warm summers and cold, snowy winters, significantly influences local lifestyles and agricultural practices. This climatic diversity, coupled with the region's unique topography, contributes to its rich biodiversity and complex hydrogeological characteristics. Iconic water bodies such as Dal Lake and Nigeen Lake, famous for their houseboats and shikaras, attract tourists from around the world. The Jhelum River, a vital waterway, flows through the district, further enhancing its natural beauty and ecological significance. A comprehensive understanding of the region's hydrogeological aspects is crucial for effective water resource management in the Kashmir Valley.

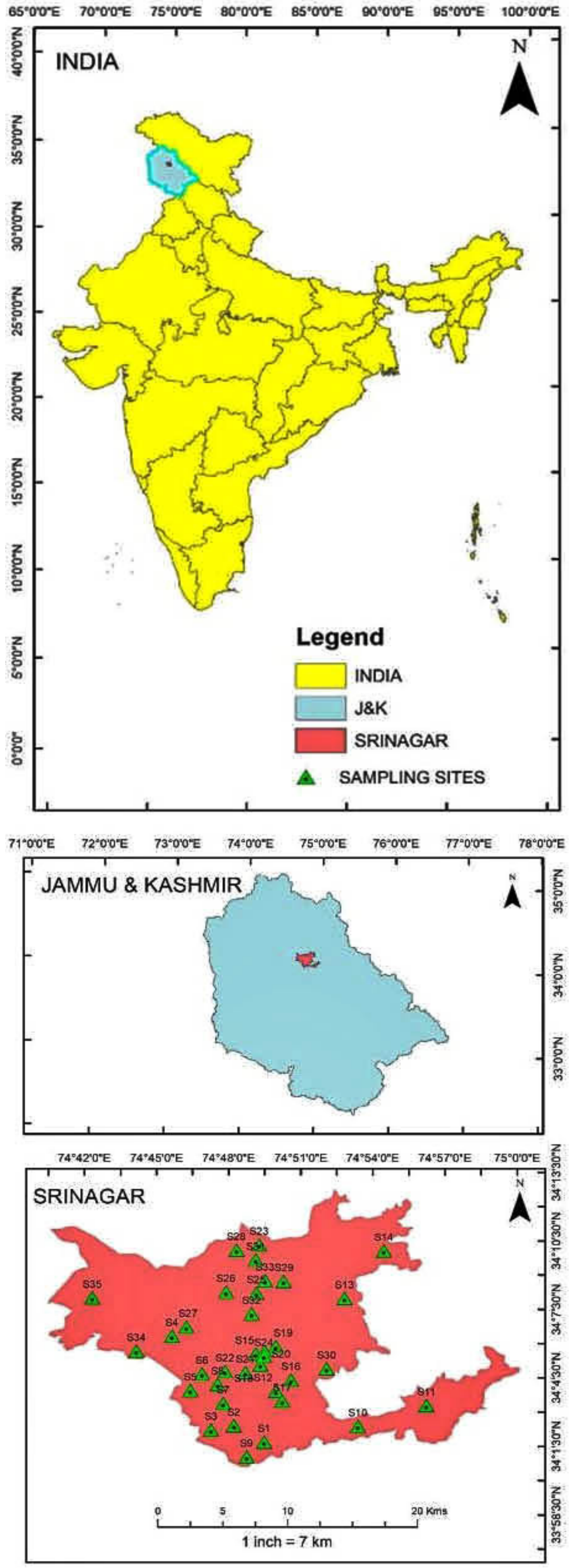

Figure 1. Srinagar study area with sampling sites

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Methodology

Thirty-five groundwater samples were collected from various tubewells within the district, with the depths of these wells ranging from 10 to 16 meters. To ensure sample integrity, sterile plastic bottles were employed for collection. Following collection, each sample was meticulously sealed, clearly labelled with relevant information such as location and then carefully transported to the laboratory for subsequent analysis. To ensure representative sampling and minimise potential contamination, each borehole was purged for over 05 minutes using existing infrastructure prior to sample collection. Standard methods outlined in APHA 2005 were employed to analyze the dissolved chemical components [16]. Water quality parameters were assessed through a combination of in situ measurements and laboratory analyses. Temperature, electrical conductivity (EC), pH, and alkalinity were determined on-site using a digital water analysis kit, incorporating digital thermometers, pH meters, and conductivity meters. In the laboratory, total dissolved solids (TDS) were calculated from the sum of cation and anion concentrations. Alkalinity and total hardness were quantified by titration with HCl and EDTA, respectively. Magnesium levels were derived from the total hardness and calcium measurements. Chloride concentrations were determined using $AgNO_3$ titration. Sodium and potassium levels were measured via flame photometry, while sulfate and iron concentrations were determined spectrophotometrically and by atomic absorption spectroscopy, respectively.

Results and Discussion

Table 1 provides a detailed overview of the physicochemical characteristics observed across the 35 distinct sampling locations. To rigorously assess the water quality at these sites and ensure adherence to established safety standards, the measured parameters were rigorously compared against the recommended guidelines stipulated by both the World Health Organization (WHO) and the Bureau of Indian Standards (BIS) [17,18]. This comparative analysis, designed to provide a comprehensive understanding of the data, is further enhanced by the inclusion of key statistical measures.

Table 2 presents a summary of these statistical analyses, including the minimum and maximum values recorded for each parameter, as well as the calculated mean and standard deviation, offering a robust statistical description of the dataset. In the study area, the pH values of groundwater varied between 6.7 and 7.6, with an average of 7.1. This pH range falls within the slightly alkaline category, which is typically viewed as beneficial for both drinking water and agricultural purposes. Slightly alkaline water is generally considered optimal for maintaining the health of crops and providing safe drinking water The electrical conductivity (EC) of the collected groundwater samples exhibited a range from 419 μS/cm to 1284 μS/cm, with a calculated mean value of 779.7 μS/cm. Electrical conductivity is a crucial proxy measurement for the total dissolved solids (TDS) present in water, effectively reflecting the overall mineral content and salinity. Elevated EC values typically suggest a higher concentration of dissolved ions and, consequently, increased salinity.

As established by Gulta, Sunita, and Saharan [19], electrical conductivity measurements can be utilized to classify water quality into distinct categories, ranging from low to medium to good, providing a valuable framework for assessment. Within this study, the highest EC reading, signifying the greatest concentration of dissolved ions, was recorded at sampling site S4. Conversely, the lowest EC value, indicative of the lowest concentration of dissolved ions, was observed at sampling location S16. The concentration of Total Dissolved Solids (TDS), encompassing all inorganic salts present in water, serves as a crucial parameter for assessing water salinity and its suitability for human consumption. Within the investigated region, TDS concentrations exhibited a considerable range, fluctuating between 311 and 899 mg/L. The average TDS value across the sampled groundwater sources was determined to be 543.46 mg/L. Based on established classification systems, such as those proposed by Catroll, Freeze and Cherry (as summarized in Table 4), all groundwater samples collected within the study area were categorized as falling within the "slightly saline" range [20,21]. This classification suggests that while the water may possess a slightly elevated salt content, it generally remains suitable for most domestic and agricultural purposes.

Total alkalinity, a crucial measure of a water body's ability to resist changes in pH, exhibited a considerable range in our study, fluctuating between 143 mg/L and 554 mg/L. This variability highlights the diverse buffering capacities observed across the sampled locations. On average, the total alkalinity was determined to be 329.9 mg/L. The highest alkalinity was observed at S18, while the lowest was found at S21. Elevated alkalinity levels are typically linked to the presence of bicarbonates and carbonates in the groundwater, which can influence the pH stability and overall water chemistry. The total hardness in the analyzed groundwater samples varied between 139 mg/L and 485 mg/L, with the mean hardness calculated to be 316.3 mg/L. The sample from location S2 exhibited the highest hardness, while the sample from location S16 showed the lowest. This hardness in groundwater is mainly due to dissolved calcium (Ca^{2+}) and magnesium (Mg^{2+}) ions, which are liberated by the weathering of soils and sedimentary rocks. Based on the classification criteria established by Sawyer and McCarthy, the groundwater hardness in the study area is categorized and presented in Table 5 [22]. The analysis indicates that a small portion, 2.85%, of the groundwater samples are classified as moderately hard, while the majority, 97.14%, fall into the hard to very hard categories. This distribution suggests that the groundwater in the area generally has a high mineral content, particularly in terms of calcium and magnesium ions, contributing to its elevated hardness levels. Calcium hardness, specifically, ranged from 44 mg/L to 135 mg/L, with an average of 80.37 mg/L. The maximum calcium concentration was recorded at S1 and the minimum at S10 and S13. It is not uncommon for natural water sources to have calcium concentrations up to 100 mg/L. In addition to calcium, magnesium hardness exhibited a considerable range, fluctuating between 10 mg/L and 48 mg/L. This variability resulted in an average magnesium concentration of 28.17 mg/L across the sampled locations. Notably, the highest magnesium concentration within the study was specifically observed at sampling location S6. Conversely, the lowest recorded level of magnesium was detected at location S16. The concentration of

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sodium ions (Na^+) in the studied samples exhibited a considerable range, fluctuating between a minimum of 21 mg/L and a maximum of 126 mg/L.

On average, the sodium concentration was found to be 52.09 mg/L. Notably, the highest concentration of sodium was observed at sampling location S1. Conversely, the lowest sodium concentrations were jointly recorded at locations S17 and S23, suggesting potential localized factors influencing sodium presence. Sodium enters groundwater primarily through the weathering of sodium-bearing rocks and minerals, such as halite (rock salt) or soda ash, as well as through anthropogenic sources like sewage and industrial effluents. Potassium ion (K^+) concentrations exhibited a significant range across the study area, fluctuating between 2 mg/L and 32 mg/L. The average K^+ concentration was determined to be 12.6 mg/L. The highest potassium levels were observed at sampling site S1, suggesting a localized source or influence contributing to elevated concentrations at this particular location. Conversely, the lowest potassium concentrations were recorded at sites S16, S21, and S30.

Within the study area, bicarbonate concentrations exhibited a notable range, fluctuating between a minimum of 105 mg/L and a maximum of 365 mg/L. This variability resulted in an average concentration of 222.4 mg/L. The highest bicarbonate level was observed at S24, and the lowest at S21. Bicarbonates are important indicators of water's buffering capacity and play a significant role in determining its overall chemical balance. In the analyzed groundwater samples, chloride (Cl^-) concentrations exhibited a notable range, spanning from a minimum of 4 mg/L to a maximum of 110 mg/L with an average of 39.8 mg/L. Chlorides are naturally occurring ions commonly found in groundwater due to the dissolution of salts such as sodium chloride, potassium chloride, and calcium chloride. Sulfate ion (SO_4^{2-}) concentrations exhibited a considerable range in the analyzed samples, varying from a minimum of 2 mg/L to a maximum of 48 mg/L, with an average of 20.6 mg/L. The highest sulfate concentration was recorded at S1, while the lowest was observed at S16, S17, and S23. Sulfate levels are often influenced by the mineralogical composition of the surrounding rocks and can affect both water quality and its suitability for agricultural purposes. The analysis of ionic composition within the study area reveals a distinct pattern in the distribution of major cations and anions. The cation dominance follows this order: calcium (Ca^{2+}) is the most abundant, followed by sodium (Na^+), magnesium (Mg^{2+}), and potassium (K^+) with the lowest concentration. For anions, bicarbonate (HCO_3^-) is the most prevalent, followed by chloride (Cl^-), with sulfate (SO_4^{2-}) being the least abundant. Iron (Fe) concentrations in the study area varied from 0.01 mg/L to 2.3 mg/L, with an average of 0.8 mg/L. The highest iron levels were recorded at S20 and S24, while the lowest was found at S11. Elevated iron concentrations in groundwater are typically associated with the dissolution of iron-bearing minerals from the surrounding rocks. Locations with higher iron levels may require treatment methods such as oxidizing filters, green-sand, or mechanical filtration to reduce concentrations to acceptable levels.

Salinity levels in the groundwater samples were evaluated using electrical conductivity (EC) and subsequently categorized using Handa's classification system, as detailed in Table 6 [23]. The analysis revealed that 51.43% of the samples fall into the medium salinity class, while 48.57% are categorized under the high salinity (permissible) class. Salinity hazard refers to the concentration of dissolved salts in irrigation water, which can harm soil quality and crop growth. It is assessed by measuring electrical conductivity (EC), which reflects the water's ability to conduct electricity and correlates with salt concentration. Analysing EC helps determine water suitability for irrigation and guide management practices to prevent soil salinization and its negative impact on agriculture. Table 7 presents the groundwater classification based on salinity hazard, indicating that 2.5% of the samples belong to class C1, 51.43% to class C2, and 48.57% to class C3. The Wilcox diagram (Figure 2) classifies water quality based on electrical conductivity (EC) and sodium percentage (Na%), where the percentage of sodium in relation to all cations is computed as percent sodium [24]. Most groundwater samples are categorized as "Excellent to Good," with a smaller portion falling into the "Good to Permissible" zone. Table 8 presents the classification of groundwater based on sodium percentage following Wilcox's 1955 criteria, showing that 11.43% of samples are in the excellent category, 85.71% of samples in the good category, and 2.85% of samples in the permissible category [24]. The Na% values range from 19.61 to 40.11, while EC values remain below 1000 µS/cm, indicating the water is suitable for irrigation and agricultural purposes due to its low salinity and moderate sodium content. The 1954 USSL Richards diagram (Figure 3) was utilized to classify groundwater samples based on their SAR (Sodium Adsorption Ratio) to evaluate their suitability for irrigation [25].

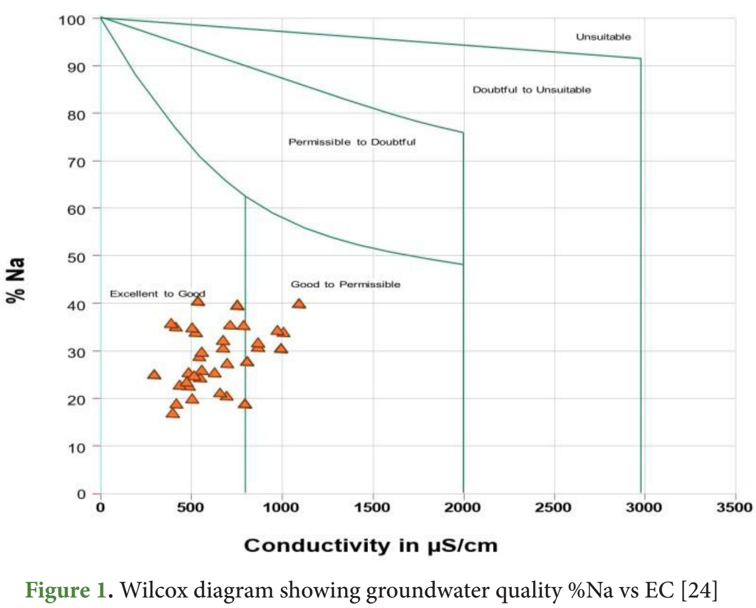

Figure 1. Wilcox diagram showing groundwater quality %Na vs EC [24]

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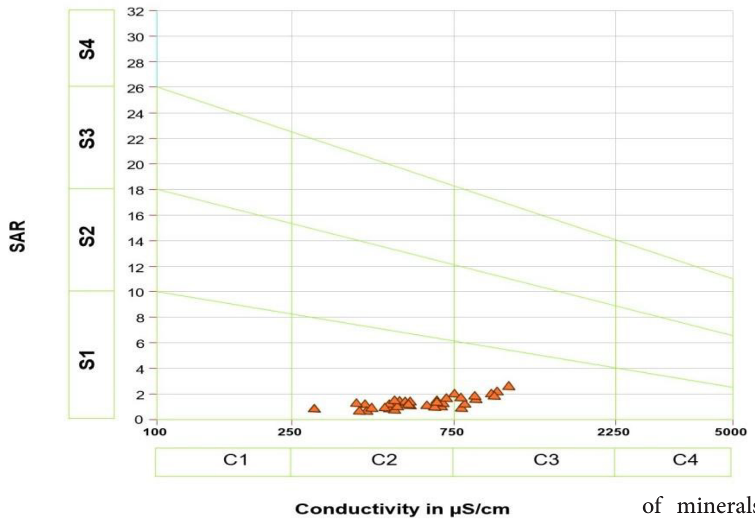

Figure 3. The US Salinity Hazard diagram [25].

The analysis showed that most of the samples fall within the C2S1 category, characterized by medium salinity and low sodium content, making them generally suitable for irrigation. A smaller number of samples were classified as C3S1, indicating high salinity with low sodium content. While these samples remain suitable for irrigation, their higher salinity necessitates careful management to prevent salt accumulation in the soil, which could adversely affect plant growth and soil structure. Table 9, using the SAR-based water classification system of Todd, categorizes all analyzed samples as "excellent," indicating their suitability for irrigation due to a low sodium hazard [26]. This suggests that, with the exception of some high-salinity areas requiring careful management, the groundwater in the study area is generally well-suited for agricultural applications. The Water Quality Index (WQI) is an essential tool for conveying water quality information to stakeholders and policymakers. A weighted arithmetic water quality index (WQI), based on the methodology of Brown et al., was calculated to evaluate groundwater quality in the Srinagar district [27]. The calculation considered several physicochemical parameters: pH, EC, TH, TA, TDS, and cation (Ca, Mg, Na, and K) and anion (HCO_3^-, Cl^-, and SO_4^-) concentrations. The computed Water Quality Index (WQI) value of 27.70, as presented in Table 10, aligns with the categorization by Brown et al., indicating that the groundwater in the Srinagar district is of good quality [28].

The Piper diagram (Figure 4) reveals that the groundwater samples predominantly fall within the Ca^{2+}-Mg^{2+}-HCO_3^- facies, representing a calcium-magnesium-bicarbonate water type and most of the samples, cluster in the Calcium-Magnesium-Bicarbonate field, indicating that calcium and magnesium are the dominant cations and bicarbonate is the dominant anion [29]. This water type is typical of regions with carbonate rock formations, such as limestone and dolomite. The clustering towards the right side of the diagram suggests a high degree of hardness, which is further supported by the dominance of calcium and magnesium ions. The samples fall within the low to moderate salinity range, with bicarbonate ions clearly dominating the anion composition. The high hardness may pose challenges for domestic and industrial use, potentially leading to scaling and other issues. However, bicarbonate-dominated waters are generally less aggressive towards pipes and structures. The minimal presence of chloride and sulfate concentrations indicates limited anthropogenic influence on the water quality. The Gibbs diagram illustrates groundwater chemistry using two ratios: $(Na^+ + K^+)/(Na^+ + K^+ + Ca^{2+})$ and $Cl^-/(Cl^- + HCO3^-)$ [30]. By plotting these ratios against TDS, the diagram reveals the dominant geochemical processes such as rock weathering, evaporation, and precipitation. In Figure 5, the data points are clustered in the "Rock Weathering Dominance" field, indicating that the water chemistry is primarily controlled by the dissolution of minerals from the surrounding rocks. This is further supported by the location of the data points being closer to the lower left corner of the diagram, which signifies lower Total Dissolved Solids (TDS) values. Overall, the Gibbs diagram suggests that the water body is likely a freshwater system with a low degree of mineralization, primarily influenced by rock weathering processes and with some localized impact from evaporation [30].

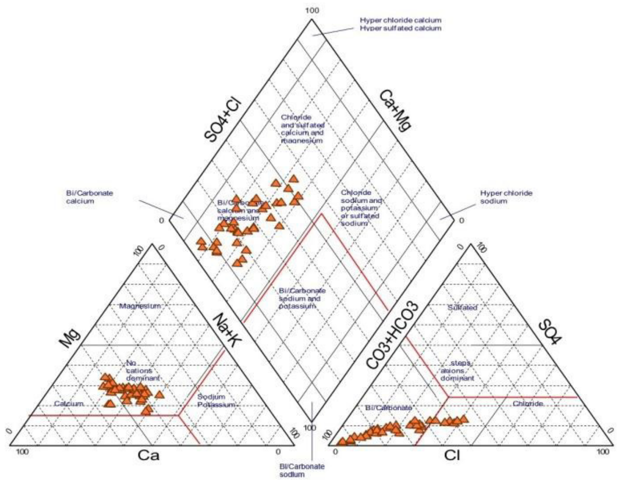

Figure 4. Piper's Trilinear Plot of Groundwater [29]

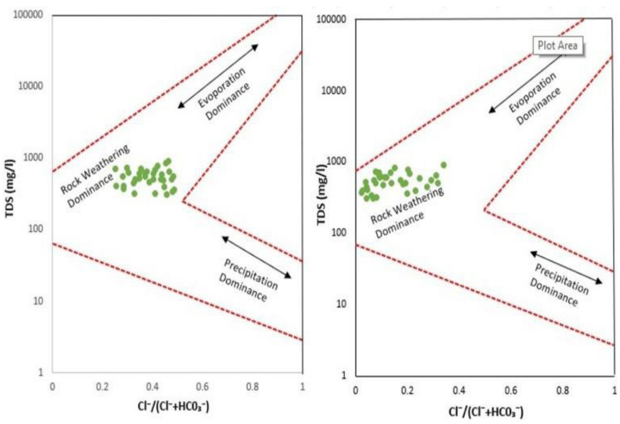

Figure 3. Gibbs Diagram [30]

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Statistical Analysis

In this study, we employed Excel to calculate key statistical parameters such as minimum, maximum, average, standard deviation, coefficient of variation, and correlation coefficient (r) for each pair of water quality parameters. This statistical analysis of experimentally determined water quality parameters provides insights into their variability, central tendency, and dispersion. By examining these parameters, we can assess the overall water quality, identify potential issues, and explore correlations between different factors. Table 2 presents a comparative analysis of water quality parameters across fifteen different locations, including temperature, pH, total dissolved solids, total hardness, electrical conductivity, turbidity, alkalinity, chloride, nitrate, calcium, magnesium, fluoride, and iron. The table includes minimum, maximum, mean, standard deviation, and coefficient of variation values for each parameter. The strength and direction (positive or negative) of a linear relationship between two variables are described by a statistical measure known as correlation. Direct correlation (positive) signifies a concurrent increase in both parameters, whereas an inverse correlation (negative) denotes that an increase in one parameter is associated with a decrease in the other. pH shows a weak and negative correlation with most parameters, indicating that its variations have minimal impact on other water quality indicators. However, it has a slight positive correlation with iron. Electrical Conductivity is strongly correlated with TDS, total hardness, calcium and magnesium, suggesting that higher EC values are primarily due to increased dissolved solids and water hardness. Similarly, TDS displays strong correlations with TH, Ca^{2+}, and Mg^{2+}, highlighting their interconnected roles in water chemistry. Total Alkalinity is predominantly driven by bicarbonate concentrations, as indicated by their strong correlation. TH is mainly influenced by the concentrations of Ca^{2+} and Mg^{2+}, which also show strong associations with EC and TDS. Sodium and potassium have moderate to weak correlations with other parameters, implying distinct sources or behaviours within the water system. For anions, bicarbonate is highly correlated with TA, while chloride and sulfate exhibit strong correlations with EC, TDS, and Na^{+}, reflecting their significant contribution to salinity. Iron, on the other hand, shows weak correlations with most parameters, indicating its variability is largely independent of the major ions or overall water chemistry.

Table 1. An overview of the physicochemical parameters

Sample No.	Location	PH	EC µS/cm	TDS mg/l	T A mg/l	TH mg/l	Ca^{2+} mg/l	Mg^{2+} mg/l	Na^{+} mg/l	K^{+} mg/l	$HCO3^{-}$ mg/l	Cl^{-} mg/l	SO_4^{2-} mg/l	Fe mg/l
S1	Nowgam	7.1	771	560	400	435	135	35	126	32	265	110	48	0.5
S2	Baghat Barzulla	7.2	1017	712	494	485	125	42	42	15	292	45	23	1.3
S3	Hyderpora	7.3	563	394	200	245	62	22	50	12	134	40	22	0.3
S4	Parimpora	6.8	1284	899	340	468	128	47	110	15	209	108	46	0.3
S5	Bemina	7.5	679	455	176	289	76	24	48	8	120	46	20	0.5
S6	Tatoo Ground	7	926	648	360	477	112	48	98	25	223	100	38	1.2
S7	Aloochi Bagh	6.7	1105	774	512	471	121	41	88	9	358	91	32	0.6
S8	Batamaloo	7	987	691	436	413	101	39	70	22	289	76	34	2
S9	Baghe Mehtab	7.2	893	625	420	247	61	23	36	5	276	29	18	0.2
S10	Panthachowk	7.3	550	365	260	216	44	19	42	27	190	47	25	0.03
S11	Khonmoh	7.1	498	320	196	259	50	18	35	23	124	11	9	0.01
S12	Raj Bagh	7.3	910	610	450	314	86	24	58	8	280	35	25	0.8
S13	Nishat	7.5	490	311	171	188	44	18	37	16	122	9	6	0.4
S14	Theed	6.9	715	405	228	311	80	27	32	15	145	7	5	0.4
S15	Khanyar	7.2	1046	732	420	443	108	42	46	9	250	21	16	0.5
S16	Gupkar	7	419	315	155	139	45	10	22	2	115	5	2	0.2
S17	Shivpora	7.2	536	375	300	223	53	22	21	4	212	5	2	0.6
S18	Khayam Chowk	6.9	925	647	554	332	82	31	50	11	324	32	26	0.3
S19	Rainawari	7.1	725	508	360	269	65	26	50	3	240	20	15	2.2
S20	Mughal Mohala	7	1126	840	428	449	104	46	86	15	286	51	28	2.3
S21	Barbarshah	7.2	756	559	143	306	78	27	46	2	105	22	12	0.1
S22	Karan Nagar	6.9	801	612	265	332	85	29	45	5	178	18	10	0.8
S23	Gulab Bagh	7	574	402	270	255	61	25	21	4	150	4	2	1.1
S24	Miskeen Bagh	7.2	1007	705	520	394	95	38	52	28	365	36	28	2.3
S25	Lalbazar	7	721	508	280	298	86	20	78	18	188	88	36	0.7
S26	Soura	7	835	585	316	345	92	28	71	24	230	75	39	0.3
S27	Palpora	7.5	728	510	350	271	79	18	39	5	254	60	31	1.2
S28	Ahmad Nagar	7.1	883	618	360	392	96	37	42	9	236	32	24	0.5

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S29	Habak	6.9	780	550	328	255	64	23	25	6	250	19	11	1.8
S30	Zeithyar	7.6	650	443	280	219	58	18	28	2	210	9	4	2.1
S31	Rangpora	7.3	695	517	364	264	66	24	35	7	243	10	6	0.2
S32	Baghwanpora	7.6	565	342	320	212	52	20	48	6	236	15	8	0.4
S33	Malbagh	7.5	670	483	230	253	65	22	32	5	179	21	12	1.2
S34	Khushipora	6.9	723	506	349	296	74	27	50	23	264	42	22	0.2
S35	Mujgund	7	735	495	310	307	80	26	64	21	242	54	36	0.5

Table 2. Statistical analysis of drinking and domestic water parameters

Parameter	Maximum	Minimum	Mean	BIS (2012)[18]	WHO (2017) [17]	Standard Deviation	Coefficient of variation
PH	7.6	6.7	7.14	6.5-8.5	6.5-8.5	0.23	3.244
EC µS/cm	1284	419	779.66	750-3000	1400	202.53	25.977
T A mg/l	554	143	329.86	200-600	300	107.99	32.739
TDS mg/l	899	311	543.46	500-2000	600-1000	150.76	27.740
TH mg/l	485	139	316.34	200-600	200	92.65	29.288
Ca^{2+} mg/l	135	44	80.37	75-200	100-300	25.03	31.142
Mg^2+ mg/l	48	10	28.17	30-150	50	9.65	34.248
Na+ mg/l	126	21	52.09	200	200	25.19	48.361
K+ mg/l	32	2	12.60			8.67	68.791
HCO3 mg/l	365	105	222.40	200		68.02	30.585
Cl^- mg/l	110	4	39.80	250	200	31.23	78.471
SO_4^{2-} mg/l	48	2	20.60	200-400	250	13.08	63.492
Fe mg/l	2.3	0.01	0.80	0.3	0.3	0.70	87.157

Table 3. Correlation coefficients (r) pertaining to water quality parameters

	PH	EC µS/cm	TDS mg/l	TA mg/l	TH mg/l	Ca^{2+} mg/l	Mg^2+ mg/l	Na^+ mg/l	K^+ $^+$mg/l	HCO $_3$ mg/l	Cl^- mg/l	SO_4^{2-} mg/l	Fe mg/l
PH	1												
EC µS/cm	-0.448	1											
TDS mg/l	-0.457	0.985	1										
TA mg/l	-0.290	0.731	0.714	1									
TH mg/l	-0.470	0.876	0.864	0.633	1								
Ca^{2+} mg/l	-0.448	0.838	0.832	0.596	0.958	1							
Mg^2+ mg/l	-0.465	0.876	0.867	0.620	0.957	0.872	1						
Na^+ mg/l	-0.383	0.588	0.588	0.365	0.709	0.771	0.645	1					
K^+ $^+$mg/l	-0.255	0.182	0.147	0.20	0.411	0.377	0.349	0.569	1				
HCO_3 mg/l	-0.246	0.670	0.658	0.962	0.549	0.524	0.533	0.349	0.228	1			
Cl^- mg/l	-0.361	0.557	0.553	0.354	0.665	0.741	0.561	0.906	0.578	0.360	1		
SO_4^{2-} mg/l	-0.337	0.611	0.603	0.464	0.673	0.736	0.570	0.865	0.636	0.470	0.942	1	
Fe mg/l	0.050	0.306	0.326	0.359	0.238	0.185	0.289	0.038	-0.051	0.405	0.022	0.046	1

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Table 4. TDS-based groundwater classification [20,21]

Water type	TDS range in mg/l	Sample %	Description
Freshwater	<50	----	Ideal for most domestic, and agricultural uses.
Slightly Saline	50-1000	100%	Acceptable for the majority of applications. Treatment may be required for certain purposes, such as drinking water with high TDS levels at the upper end of this range.
Moderately Saline	1000-3000	----	Depending on the intended application, treatment could be necessary. Possible restrictions on irrigation because of concerns of salinity.
Brackish water	3000 –10,000	----	substantial restrictions for the majority of applications. Water for drinking has to be treated. Many crops cannot be irrigated using this method.
Saline water	10,000 -100,000	----	Not appropriate for the majority of agricultural and domestic uses. Levelsofsalinity necessitate extensive treatment procedures.
Brine water	>100,000	----	Inappropriate for all uses.

Table 5. Groundwater quality classification based on total hardness [25]

TH mg/l	Water type	Sample %	Description
<75	Soft	----	Suitable for most domestic uses and industrial applications because of its enhanced soap lathering and low scale formation
75-150	Moderately Hard	2.85%	Acceptable for the majority of applications and may cause pipes and boilers to scale slightly.
150-300	Hard	48.57%	May result in mild scaling of appliances and pipes. Water softening could be necessary for specific industrial operations.
>300	Very Hard	48.57%	Major scaling problems with home appliances, boilers, and pipes. Water softening is frequently advised.

Table 6. EC-based water classification [23]

ECμS/cm	Water salinity	Sample Percentage
0-250	Excellent quality with low salinity	-----
251-750	Good Quality with medium Salinity	51.43%
751-2250	High Salinity Permissible Quality with high Salinity	48.57%
2251-6000	Very High Salinity	-----
6001-10000	Extensively high	-----
10001-20000	Brines weak concentration	-----
20001-50000	Brines moderate concentration	-----
50001-100000	Brines High concentration	-----
>100000	Brines extremely high concentration	-----

Table 7. Salinity Hazard classification

Salinity Hazard Class	EC (μ/cm)	Water Quality	Sample Percentage
C1	100-250	Excellent	----
C2	251-750	Good	51.43%
C3	751-2250	Doubtful	48.57%
C4, C5	>2250	Unsuitable	----

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Table 8. % Sodium water class [24]

%Na	Water type	Sample Percentage	Suitability for Irrigation
<20%	Excellent	11.43%	Suitable for most crops and soils.
20-40%	Good	85.71%	Although generally appropriate, some soil types require monitoring to identify any salt accumulation.
40-60%	Permissible	2.85%	To prevent soil deterioration, cautious management techniques like improved leaching can be required
60-80%	Doubtful	----	Limited appropriateness; requires the use of crops that can withstand salt and adequate drainage.
>80%	Unsuitable	----	High salt hazards and possible issues with soil structure make it inappropriate for irrigation.

Table 9. SAR-based classification of waters [26]

Water Type	SAR Values	Sample Percentage	Description
Excellent	< 10	100%	Low sodium hazard, excellent for irrigation.
Good	10--18	----	Low to medium sodium hazard, excellent for the majority of crops
Doubtful	19 -26	----	Medium sodium hazard, crops that are sensitive to sodium may need to be managed carefully.
Unsuitable	> 26	----	Severe sodium hazard, not recommended for irrigation

Table 10. Water quality index of groundwater samples collected from srinagar

Parameter	BIS (Sn)	1/Sn	Σ1/Vs	K=1/ (Σ1/Sn)	Wn=K/Vs	Ideal value (Vi)	Mean conc. Value (Vn)	Vn/Sn	Qn=100* (Vn/Sn)	WnQn
PH	8.5	0.118	3.530	0.283	0.033	7	7.14	0.84	84.03	2.80
EC μS/cm	750	0.001	3.530	0.283	0.000	0	779.66	1.04	103.95	0.04
T A mg/l	200	0.005	3.530	0.283	0.001	0	543.46	2.72	271.73	0.38
TDS mg/l	500	0.002	3.530	0.283	0.001	0	329.86	0.66	65.97	0.04
TH mg/l	200	0.005	3.530	0.283	0.001	0	316.34	1.58	158.17	0.22
Ca^{2+}mg/l	75	0.013	3.530	0.283	0.004	0	80.37	1.07	107.16	0.40
Mg^{2}+mg/l	30	0.033	3.530	0.283	0.009	0	28.17	0.94	93.90	0.89
Na+ mg/l	200	0.005	3.530	0.283	0.001	0	52.09	0.26	26.04	0.04
Fe mg/l	1	1.000	3.530	0.283	0.283	0	0.80	0.80	80.11	22.70
HCO3	200	0.005	3.530	0.283	0.001	0	222.40	1.11	111.20	0.16
Cl^{-}mg/l	250	0.004	3.530	0.283	0.001	0	39.80	0.16	15.92	0.02
SO_4^{2-} mg/l	200	0.005	3.530	0.283	0.001	0	20.60	0.10	10.30	0.01
		Σ1.197			Σ0.339					Σ27.70

Conclusions

The principal aim of this study was the comprehensive evaluation of the physicochemical properties and general quality of groundwater within the designated region. A total of 35 locations were surveyed, and the findings suggest that the groundwater quality is generally favourable, based on the analysis of various monitored elements and physicochemical parameters. The pH values, ranging from 6.7 to 7.6, confirm that the water is slightly alkaline, making it favourable for a broad spectrum of uses, including human consumption and agricultural applications. EC and TDS measurements classify the groundwater as slightly saline, indicating its suitability for irrigation and agricultural use. However, localized areas with higher salinity may require careful management to mitigate potential soil quality impacts. The water in the study area is predominantly hard to very hard, with Ca^{2+} being the dominant cation, and HCO_3^{-} as the primary anion, a pattern confirmed by the Piper diagram. The order of cationic abundance is Ca > Na > Mg > K, whereas the order of anionic abundance is HCO_3 >Cl > SO_4. Carbonate weathering exerts a primary influence on groundwater chemistry in the study area, although silicate weathering also contributes to the presence of some dissolved ions. Analysis using the Gibbs diagram further reinforces the conclusion that rock weathering is the dominant control on groundwater chemistry, indicating minimal anthropogenic impact and suggesting a largely natural, unpolluted system.

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Evaluation of salinity and sodium hazards, employing the Wilcox and USSL Richards diagram methodologies, demonstrates that the majority of the analysed groundwater samples present conditions suitable for irrigation practices [24,25]. However, some areas with higher salinity require careful management to avoid potential negative impacts on soil quality. Evaluation using the Water Quality Index (WQI) suggests that groundwater in the study area is generally suitable for a variety of applications, including domestic and agricultural uses. This suitability is supported by the fact that most samples met the quality standards established by the WHO and BIS [17,18]. However, the study also underscores the presence of localized issues, such as high hardness and salinity, which may require targeted management strategies. While the majority of groundwater samples were deemed acceptable for drinking, certain locations exhibited elevated iron levels exceeding the permissible limits. This suggests a need for specific treatment interventions, such as the use of oxidizing filters, green-sand filters, or mechanical filtration, to mitigate iron contamination and ensure water safety for human consumption. The findings emphasize the importance of continued monitoring and proactive management of groundwater resources to address site- specific challenges. Implementing appropriate water treatment technologies and sustainable management practices will be crucial to maintaining the quality and usability of groundwater for both current and future needs. This study provides valuable insights into groundwater quality in the region and highlights areas requiring attention to sustain its use for domestic, agricultural, and other purposes.

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