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Hydrogeochemical evaluation of groundwater characteristics across district Budgam, Kashmir, India

Younis Ahmad Ganaiee, Rouf Ahmad Dar and SP Singh

Abstract
A hydrogeochemical assessment was conducted in the Budgam district of Jammu and Kashmir, India, to analyze the characteristics and the geochemical composition of groundwater. Forty groundwater samples underwent comprehensive hydrogeochemical analysis, including determination of pH, electrical conductivity (EC), total hardness, total dissolved solids (TDS), and major cation and anion concentrations. Additionally, calculations were performed to determine the salinity index, salinity hazard, percent sodium (%Na), and sodium adsorption ratio (SAR). This hydrogeochemical assessment revealed that the groundwater in the study area adheres to established standards, making it generally suitable for various geochemical applications. However, the analysis also identified a few localized areas with elevated concentrations of iron and total hardness that require specific treatment methods. While sodium concentrations and salinity levels remained within acceptable limits for irrigation across most of the investigated region, a proactive approach to sustainable water resource management necessitates continued monitoring of salinity and nitrate concentrations, particularly in shallow wells.

Keywords: Hydrogeochemical assessment, groundwater, salinity hazard, percent sodium, sodium adsorption ratio, irrigation, sustainable water resource management, Budgam

Introduction

One of the main sources of water supply around the globe is groundwater (Todd, 1980). It makes up the majority of our freshwater resources. Of all the water resources on Earth, groundwater contributes only 0.6%. In developing nations such as India, about 80% of the residential water supply is derived from groundwater in rural regions, while only 50% comes from urban areas. In the Indian subcontinent, groundwater represents a significant safe drinking water supply (Acworth 1987; Ahn and Chon 1999) [1, 2]. However, at the moment, the combined impacts of over-extraction, chemical pollution, etc. are causing the quality of groundwater to decline. Numerous sources of contamination, including domestic and municipal solid wastes, industrial wastes, landfill leachate, reckless land disposal of human and animal waste, inadequate on-site sanitation facilities, septic tank systems, fertilizers and pesticides used during irrigation, etc., seriously threaten the ground (Sunil Kumar, 2008; Kalpana and Elango, 2013; Ewusi *et al*., 2013) [23, 13, 8]. A combination of anthropogenic activities, the dissolution of soluble mineral species, and groundwater's interaction with rocks regulate the chemistry of the groundwater (Rao, 2001; Umar and Ahmed, 2007) [18, 26]. Major regulating variables for groundwater chemistry include oxidation-reduction and biochemical reactions, as well as geochemical mechanisms such as dissolution, hydrolysis, precipitation, adsorption, and ion exchange (Mathess 1982) [15]. The enhancement of human health and economic growth are significantly influenced by groundwater supplies. When it comes to microbiological pollution, it is thought to be less dangerous than surface water sources; nonetheless, in recent decades, the presence of geogenic pollutants has raised concerns (Singh *et al*. 2017) [21]. Although the local geology and aquifer minerals frequently regulate groundwater quality, human activity can nonetheless have an impact on it. In addition to geogenic pollutants, human activities such as accelerated urbanization, unplanned development, inadequate waste management, and other demographic shifts have also had an impact on groundwater, affecting its quantity and quality (Bhatt *et al*., 2021) [4]. Consequently, in many regions of the nation, the deteriorating groundwater leads to the development of several chronic diseases, including cancer, bronchitis, hemochromatosis, fluorosis, and arsenicosis (Mukherjee *et al*. 2019) [16]. In order to evaluate groundwater quality and determine its appropriateness for different purposes, we conducted hydrochemical research in the Budgam area of India.

Study Area

Budgam is one of the six districts that make up the Kashmir Valley. It is located at an average height of around 1610 meters above mean sea level, between the latitudes of 33° 20' and 34° 54' North and the longitudes of 73° 55' and 75° 35' East (Figure 1 outlining the study area of Budgam). Budgam, which covers 1371 square kilometres and includes nine tehsils (Budgam, Beerwah, Chadoora, Khansahib, Khag, Charisharief, B.K. Pora, Narbal, and Magam), has three sub-districts: Khan Sahib, Beerwah, and Chadoora. From southwest to northeast, the area consists of the lofty Pir Panjal and flat-topped areas as foothills and plains. The area displays three primary geological formations. Initially, the pre-Karewa consolidated hard rock is observable on the Pir Panjal hills. Secondly, the Plio-Pleistocene Karewas formation is primarily located in the valley area. Lastly, the recent to sub-recent alluvium overlays the Karewas. The Karewas formation, in conjunction with Quaternary and Tertiary alluvium, is composed of alternating layers of sand, silt, gravel, and clay, occasionally interspersed with glacial boulder beds at different levels. These formations significantly impact the groundwater dynamics in the region, playing a vital role in supporting the local water supply system. Loamy soil, Karewa soil, and poorly developed mountain soil are the three main types of soil found in the region (Raza *et al*., 1978). The mean annual temperature in Budgam is 20.2°C, indicating a temperate climate. The region has considerable snowfall in the winter, with an average rainfall of 669.1 mm.

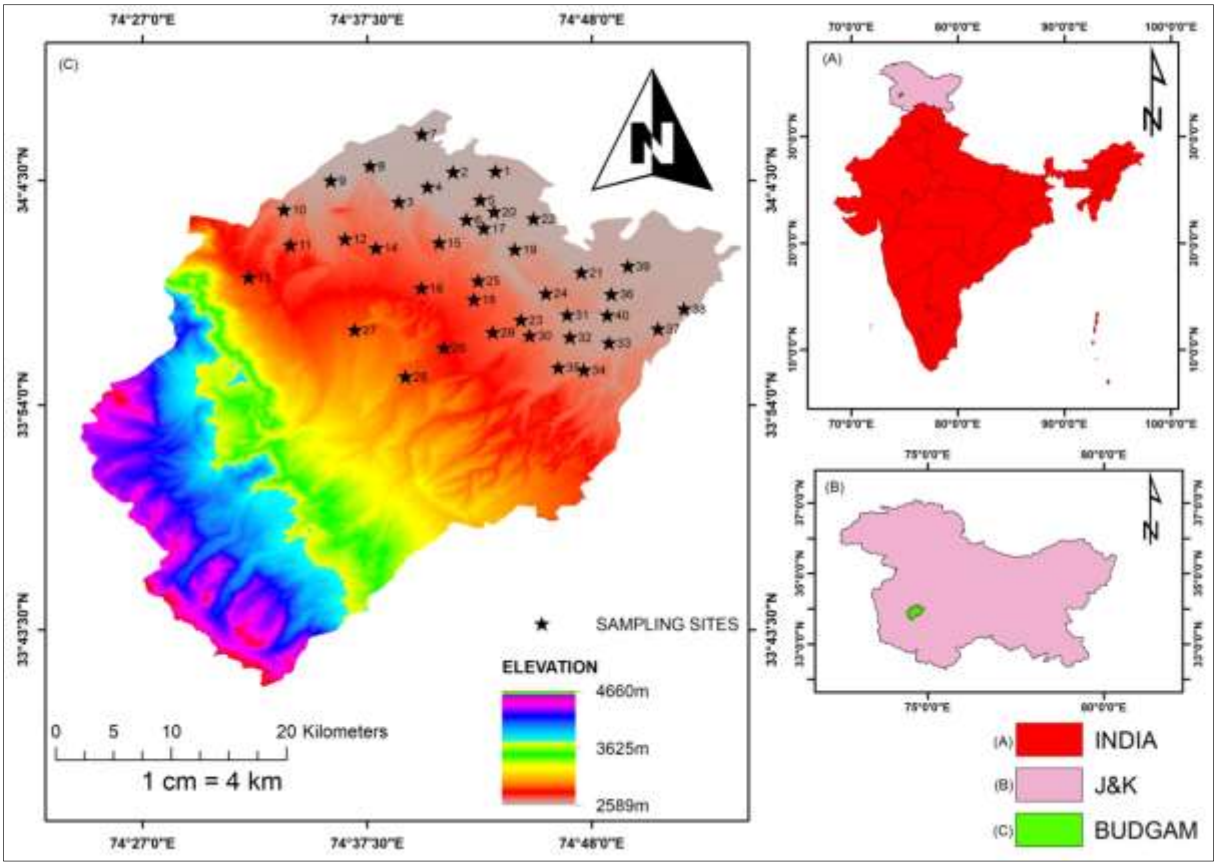

Fig 1: Illustrates the study area and sampling sites of Budgam

Methodology

To obtain a comprehensive understanding of the region's geochemistry of groundwater, a strategically designed network of 40 sampling stations was established within key villages/blocks across the study area during the summer season. High-density polyethylene (HDPE) bottles were used to collect the samples, which were then properly labelled, sealed, and brought to the lab for examination. Prior to sample collection, water from the wells was pumped out using the existing infrastructure for 2 minutes. All the collected samples underwent analysis for several physicochemical parameters, including temperature, pH, electrical conductivity (EC), turbidity, total alkalinity (TA), total dissolved solids (TDS), total hardness (TH), Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, NO_3^{-}, SO_4^{2-}, PO_4^{3-}, and iron content. The analysis of the water sample was carried out using the standard analytical procedures described by the American Public Health Association (APHA, 2005) [3]. Digital thermometers, standard pH meters, and conductivity meters were used to test the temperature, pH, and electrical conductivity (EC) on the spot. Total dissolved solids (TDS) were determined by calculating the combined concentrations of total cations and total anions in the samples (TZ concentration). Alkalinity was measured using HCl titration. Total hardness was analyzed through titration using standard EDTA (ethylenediamine tetraacetic acid). Magnesium (Mg^{2+}) content was calculated based on the total hardness and calcium (Ca^{2+}) levels. Iron was determined by the colorimetric method and Na^{+} and K^{+} were determined by flame emission photometry, and the chloride (Cl^{-}) concentration was determined using standard $AgNO_3$ titration. The concentrations of nitrate, chloride, sulfate, and phosphate in the water samples were determined using spectrophotometric analysis.

Results and Discussion

Table 1: Physicochemical characteristics of different well sampling sites in Budgam

S. No.	Sample Sites	PH	EC µS/cm	T A mg/l	TDS mg/l	TH mg/l	Ca mg/l	Mg mg/l	Cl mg/l	NO mg/l	Fe mg/l	Namg /l	K mg/l	SOmg /l	POmg /l	% Na meq/l	SAR meq/l
1.	Hajibagh	7.2	837	365	580	391	105	10	65	21	1	75	17	46	0.1	37.88	1.87
2.	Daharmunah	7.1	989	530	690	519	121	16	80	25	1.5	89	20	60	0.2	37.34	2.02
3.	Bandgam	6.8	873	147	621	539	152	20	50	11	1.4	79	16	30	0.1	29.41	1.6
4.	Chatabugh	7	864.6	490	789.3	410	100.2	29	71	19	0.5	78	17	47	0.1	34.13	1.77
5.	Haran	7.3	621	355	564.4	438	120	19	49	21	0.3	56	12	48	0.1	26.64	1.25
6.	Nasrulapora	7.1	850	355	610	366	104	19	25	16	0.2	77	15	55	0.3	35.6	1.82
7.	Narbal	7.1	715	220	465	320	109	24	45	22	0.7	64	14	38	0.01	29.77	1.45
8.	S K Pora	7.2	572.9	325	520	312	88	20	35	16	0.2	52	11	39	0.2	29.64	1.3
9.	Peth Makhama	7.2	327.4	175	297.8	196	58	9	40	15	0.01	29	7	48	0.25	28.38	0.94
10.	Palpora	7.9	300	160	275	165	45	13	50	9	0.2	27	6	60	0.02	28.6	0.91
11.	Iskanderpora	6.8	297	145	244	135	49	6	50	8.5	0.1	27	3	40	0.05	29.86	0.97
12.	Chewdara	7.3	543.2	216	493.4	230	68	11	40	12	0.1	49	11	60	0.2	35.95	1.45
13.	Khag	7.9	200	131	140	275	71	16	30	8.5	0.2	18	4	65	0.05	15.41	0.5
14.	Otligam	7.9	239	272	145	250	69	13	80	10	0.01	22	5	82	0.03	19.38	0.64
15.	Labertal	7.4	771	401	692	441	119	35	65	19	0.7	69	15	56	0.09	27.74	1.43
16.	Hard Wail	7	497	231	357	295	103	14	40	15	0.5	45	10	50	0.03	26.02	1.1
17.	Mirgund	6.9	699	135	469	396	98.5	16	40	14	0.1	63	14	31	0.1	33.21	1.55
18.	Handjan	7	692	196	618.6	340	88	21	25	10	0.75	62	11	30	0.1	32.74	1.54
19.	Ompora Colony	7.6	563	270	393	300	51.2	31	25	12	0.3	77	17	20	0.1	42.57	2.1
20.	Galwanpora	7	927	336	691	423	108	31	61	22	0.3	83	19	63	0.25	34.03	1.81
21.	Gagoo Humhama	7.3	563	200	394	300	80	19	70	17	1.1	51	10	28	0.25	30.81	1.33
22.	Narkara	7.2	813	215	689	546	91	19	66	23.5	1.1	73	16	28	0.05	37	1.82
23.	Munpopy	7.4	612	291	479	253	81	9	55	17	0.4	55	12	34	0.2	36.08	1.55
24.	Naru	7.1	578.5	260	520.9	240	63	15	65	15	0.4	52	8	24	0.1	36.04	1.53
25.	Mamath	7.5	572	300	400	320	100	13	30	12	1	51	11	20	0.1	29.21	1.27
26.	Shamsabad	7.1	525	144	476	268	74	14	30	10	0.1	47	9	28	0.1	31.95	1.31
27.	kralnewa	7.2	245	295	181	272	94.5	11	54	10	0.1	22	5	28	0.08	16.18	0.57
28.	Balpora Khaipora	7.6	160	200	112	225	91	13	55	8	0.1	14	3	30	0.05	10.89	0.36
29.	Kreimshore	7.9	180	225	126	250	89	14	75	12	0.2	16	4	25	0.1	12.49	0.42
30.	Hushroo	7.4	501	201	371	301	67	31	45	17	0.2	45	10	44	0.1	27.3	1.14
31.	Lalgam	7.1	423	105	244	354	108	34	48	14.5	0.2	33	7	45	0.1	16.47	0.71
32.	Ropora	6.9	542	182	402	440	112	18	55	14	0.1	49	8	34	0.1	24.84	1.13
33.	Dowlatpora	7.4	573	298	401	252	123	13	70	17	0.7	52	11	38	0.1	26.08	1.19
34.	Nagum	6.8	415	125	389	310	103	16	55	10.5	0.01	37	8	22	0.01	21.94	0.9
35.	Zoohama	6.7	478	135	419	292	72.5	14	55	12	0.2	43	10	35	0.06	30.83	1.21
36.	Hassipora	7.77	894	382	724	325	91.5	14	60	15	0.1	80	14	46	0.09	40.16	2.06
37.	Kuzwaira	7.92	958	415	825	397	114	21	85	20	0.01	86	19	50	0.05	36.3	1.94
38.	Khanda	7.4	991	357	801	390	121	20	75	22	0.25	89	20	46	0.2	36.32	1.98
39.	B K Pora	7.1	771	400	194	346	78.4	28	80	22	0.35	69	15	30	0.25	35.26	1.7
40.	Wathoora	7.3	730	354	688	235	90	16	60	19.5	0.1	66	10	45	0.1	35	1.68

Table 1 summarizes the physicochemical characteristics that were generated during the analysis of the 40 sampling sites. To evaluate their adherence to regulations, these parameters have been compared against the established standard permissible limits set by reputable organizations such as the World Health Organization (WHO 2011) and the Bureau of Indian Standards (BIS 2012). This comparison is presented in Table 2, which includes statistical analysis detailing the minimum, maximum, mean, and standard deviation. In the study area, groundwater exhibits a pH range of 6.7 to 7.9, with an average of 7.2, indicating a slightly alkaline nature. Notably, all measured pH values fall comfortably within safe limits (Figure 2). Electrical conductivity (EC) exhibited a range of 160 to 991 µS/cm, with a mean value of 602 µS/cm (Figure 3). This data suggests the groundwater within the study area can be broadly classified as slightly saline, potentially rendering it suitable for a diverse range of applications. The considerable fluctuation in EC is primarily attributed to regional geochemical processes. Higher EC values are indicative of elevated salinity and mineral content in groundwater, typically associated with low runoff, high infiltration, and discharge water characteristics. Conversely, lower EC values are commonly linked to elevated topography, increased runoff, reduced infiltration recharge, and minimal salt enrichment. Total alkalinity (TA) exhibited a range of 105-530 mg/L $CaCO_3$, with a mean value of 263.4 mg/L $CaCO_3$. These findings suggest a moderate buffering capacity within the groundwater system. Total dissolved solids (TDS), encompassing all inorganic salts, serve as an indicator of water salinity and suitability for human consumption. TDS levels in the investigated region varied between 112 and 825 mg/L, with an average of 462.2 mg/L. Catroll (1962) [6] and Freeze & Cherry (1979) [10] have classified the nature of groundwater based on TDS as given in Table 3. Water collected from the study area exhibited total hardness ranging from 135 to 546 mg/L, with an average of 326.4 mg/l. Based on Sawyer and McCarthy's (1967) [20] criteria, the study area's groundwater hardness is categorized and outlined in Table 4. As per this classification, the groundwater in the study area ranged from moderately hard to very hard. Specifically, 2.5% of samples are classified as moderately hard, 42.5% as hard, and 55% as very hard, indicating that the majority of samples fall into the very hard category. They require some treatment methods like ion exchange, reverse osmosis, and chemical precipitation, each with its own unique environmental and cost considerations. The presence of calcium, magnesium, and other metal ions contributes to the total hardness (TH) of groundwater. Some groundwater samples exhibit TH levels surpassing TA, indicating the presence of noncarbonate hardness that is challenging to remove. The variation in total alkalinity, total dissolved solids, and total hardness among the sample sites is illustrated in Figure 4. Calcium ions dominated the cation chemistry in the study area, ranging from 45 to 152 mg/L, with an average of 23.4 mg/l. Groundwater enrichment with calcium originates from various sources, such as minerals, rocks, carbon dioxide, ion exchange, and the presence of carbon dioxide in the soil zone. Magnesium commonly occurred in groundwater alongside calcium, with Mg^{2+} concentrations ranging from 6 to 35 mg/L and averaging 18.1 mg/L. Figure 5 illustrates variations in calcium and magnesium among the sample sites. The sodium (Na^{+}) concentration ranged from 14 to 89 mg/L, averaging 54.2 mg/l, while the potassium (K^{+}) concentration varied between 3 and 20 mg/l, with an average of 11.3 mg/l. Figure 6 illustrates variations in sodium and potassium among the sample sites. Within the study area, the cations occurred in the order of abundance: $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$. Iron ($Fe^{2+}$) concentrations ranged from 0.01 to 1.5 mg/L, with an average of 0.3 mg/L. However, certain locations exhibited iron content exceeding recommended limits. Common treatment methods for elevated iron levels in groundwater include oxidation and filtering, ion exchange, and greensand filtration. The phosphate concentration ranged from 0.01 to 0.3 mg/L, averaging 0.11 mg/L. Figure 7 illustrates the variation in iron and phosphates. Chloride, a significant anion in groundwater, can originate from leaching, mineral weathering, and anthropogenic sources. Elevated chloride concentrations in groundwater can lead to a salty taste and contribute to kidney stone formation. In the study area, chloride (Cl^{-}) concentration ranged from 25 to 85 mg/L, with an average of 53.8 mg/L. Sulfate, sourced from both geogenic and anthropogenic origins, is highly concentrated in groundwater, rendering it unsuitable for use due to its elevated levels. Its concentration varied from 20 to 82 mg/L, with an average of 41.2 mg/L. Within the study area, samples collected from shallow-depth wells predominantly exhibit higher concentrations of chloride (Cl^{-}), nitrate (NO_3^{-}), and sulfate (SO_4^{2-}). Nitrates, a major groundwater pollutant, are on the rise and pose health risks such as methaemoglobinaemia, gastric issues, and cancer. Nitrate (NO_3^{-}) concentration within the study area ranges from 8 to 25 mg/l, with a mean of 15.3 mg/l. The variation in total alkalinity, total dissolved solids, and total hardness among the sample sites is illustrated in Figure 8. Despite the need for treatment for iron and total hardness, all parameters within the study area comply with the permissible limits set by WHO (2017) and BIS (2012).

Salinity hazard (the total concentration of soluble salts) in irrigation water can be characterized in terms of specific conductance to aid in diagnosis and categorization. Table 5 shows the classification of groundwater by salinity hazard. The salinity hazard classes reveal that 12.5% of the samples in the research fall into the class C1 category, 57.5% of samples fall into class C2, and 30% of samples fall into the class C3 category. Electrical conductivity (EC) measurements were employed to calculate the salinity index for each groundwater sample. Subsequently, the samples were classified based on Handa's established classification scheme (1969) as presented in Table 6. Among the samples collected from the study area, 5 fall under the low salinity class, 23 fall under the medium salinity class, and 12 fall under the high salinity class (permissible). The Wilcox (1995) [27] and Eaton (1950) [7] methods classify and interpret the chemical composition of groundwater for irrigation, with percent sodium being a key parameter. Percent sodium is determined as the proportion of sodium relative to total cations, calculated using a specific formula.

$$\%Na = (Na + K) / (Na + K + Mg + Ca) \times 100$$

High sodium concentrations in irrigation water lead to absorbed sodium ions by clay particles, displacing Mg^{2+} and Ca^{2+} ions, reducing permeability, and resulting in poor internal drainage, restricted air and water circulation, and hard soils. An assessment of sodium (Na%) concentration indicated a spectrum of values ranging from 10.89 to 42.57 milliequivalents per litre (meq/l), with an average of 29.6 meq/l. Referencing the Wilcox diagram (Figure 9), a conventional graphical aid for evaluating irrigation water quality confirms that all samples are situated within the excellent to good classifications. This favourable result indicates a low sodium hazard and suggests a minimal risk of sodium-induced soil problems. The classification of groundwater concerning percent sodium based on Wilcox's 1955 [27] and Eaton's 1950 [7] is shown in Table 7, and it was found that 15% of samples belong to the excellent category, 80% of samples fall in the good category and 5% fall in the permissible category. The Sodium Adsorption Ratio (SAR) is a key measure for assessing this risk in irrigation. SAR compares sodium to calcium and magnesium levels in the water, indicating its potential to degrade soil. SAR helps predict sodium hazards, especially in high-carbonate waters lacking residual alkali. The formula to calculate SAR is.

$$SAR = Na / \sqrt{(Ca + Mg) / 2}$$

Analysis of the Sodium Adsorption Ratio (SAR), a crucial parameter for irrigation water quality assessment, revealed a favourable range across all sampling locations. The assessment of Sodium Adsorption Ratio (SAR) values revealed a spectrum ranging from 0.36 to 2.1 milliequivalents per litre (meq/L), with an average SAR value of 1.34 meq/L. Importantly, all recorded SAR values fell below 10 meq/L, placing them in the S1 category on the

USSL (US Salinity Laboratory 1954) Salinity Hazard Diagram (Figure 10). This classification, as indicated in widely accepted irrigation water quality standards, indicates a low sodium and salinity hazard for irrigation. The Wilcox diagram analysis indicates the tested water source falls within a zone signifying excellent irrigation suitability. This aligns with established guidelines, translating to minimal sodium and salinity hazards. Consequently, the risk of sodium accumulation in the soil, detrimental to soil structure and hindering plant growth, is minimal (Table 8).

Using data from SAR, the United States Salinity Laboratory (USSL) developed Richard's diagram in 1954 as a visual aid for assessing the suitability of groundwater for irrigation. This schematic, depicted in Figure 10, illustrates the chemical composition of the region's groundwater. Among the samples examined, 12 are classified as C3S1, denoting high salinity and low sodium content. Additionally, 5 samples are categorized as C1S1, indicating low levels of both salinity and sodium. The majority, comprising 23 samples, fall under the classification of C2S1, suggesting medium salinity and low sodium levels.

Table 2: Statistical analysis of different parameters for drinking and domestic purposes

Parameter	Minimum	Maximum	Mean	BIS (2012)	WHO (2017)	Standard Deviation
pH	6.7	7.9	7.2	6.5-8.5	6.5-8.5	0.33
Electric Conductivity	160	991	602	750-3000	1400	239
(µS/cm)						
T Alkalinity (mg/l)	105	530	263.4	200-600	----	106.4
TDS (mg/l)	112	825	462.2	500-2000	600-1000	201.3
T Hardness	135	546	326.4	200-600	200	95.7
Ca (mg/l)	45	152	91.3	75-200	100-300	23.4
Mg (mg/l)	6	35	18.1	30-150	50	7.2
Na (mg/l)	14	89	54.2	200	200	21.7
K (mg/l)	3	20	11.3	----	----	4.8
Chloride (mg/l)	25	85	53.8	250-1000	250	16.7
Sulfate (mg/l)	20	82	41.2	200-400	250	14.2
Phosphate (mg/l)	0.01	0.29	0.1	0.5-5	----	0.07
Nitrate (mg/l)	8	25	15.3	45	50	5.3
Fe (mg/l)	0.01	1.5	0.3	0.3	0.3	0.3

Table 3: Classification of groundwater based on TDS (Catroll 1962; Freeze & Cherry 1979) [6, 10]

Type of water	Range of TDS in mg/l	% of Samples	Description
Freshwater	<50	NIL	Suitable for most domestic, agricultural, and industrial uses.
Slightly Saline	50-1000	100%	Generally acceptable for most uses. May require treatment for specific purposes like drinking water with high TDS values at the upper end of this range.
Moderately Saline	1000-3000	----	May require treatment depending on the intended use. Potential limitations for irrigation due to salinity concerns.
Brackish water	3000 - 10,000	----	Significant limitations for most uses. Requires treatment for drinking water. Unsuitable for irrigation of many crops.
Saline water	10,000-100,000	----	Unsuitable for most domestic and agricultural purposes. High salinity levels require extensive treatment processes.
Brine water	>100,000	----	Unsuitable for all purposes

Table 4: Classification of groundwater quality based on Total hardness (Sawyer and McCarthy 1967) [20]

TH mg/l	Classification	% of Samples	Description
<75	Soft	NIL	Ideal for most domestic purposes and industrial applications due to lower scale formation and easier lathering with soap.
75-150	Moderately Hard	12.5%	Generally acceptable for most uses. May cause slight scaling in boilers and pipes.
150-300	Hard	42.5%	Can cause moderate scaling in pipes and appliances. May require water softening for certain industrial processes.
>300	Very Hard	55%	Significant scaling issues in pipes, boilers, and household appliances. Water softening is often recommended.

Table 5: Showing salinity hazard classes

Salinity Hazard Class	EC (µ/cm)	Quality	Percentage of samples
C1	100-250	Excellent	12.50%
C2	250-750	Good	57.50%
C3	750-2250	Doubtful	30%
C4 and C5	>2250	Unsuitable	----

Table 6: Classification of waters based on EC (Handa 1969) [11]

ECµS/cm	Water salinity	Percentage
0-250	Low Salinity (Excellent Quality)	12.50%
251-750	Medium Salinity (Good Quality)	57.50%
751-2250	High Salinity (Permissible Quality)	30.00%
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: Sodium percent water class (Wilcox 1955, and Eaton's 1950) [27, 7]

%Na	Water Class	Percentage of samples	Suitability for Irrigation
<20%	Excellent	15%	Suitable for most crops and soils
20-40%	Good	80%	Generally suitable, but requires monitoring for potential sodium accumulation in specific soil types
40-60%	Permissible	5%	May require careful management practices like increased leaching to prevent soil degradation
60-80%	Doubtful	----	Limited suitability; requires good drainage and salt-tolerant crops
>80%	Unsuitable	----	Not recommended for irrigation due to high sodium hazard and potential soil structure issues

Table 8: Classification of waters based on SAR values (Todd 1959) [24]

Water Type	SAR Values	% of samples	Description
Excellent	< 10	100%	Ideal for irrigation; low sodium hazard
Good	10--18	-----	Suitable for most crops; low to medium sodium hazard
Doubtful	19 - 26	-----	May require careful management for sodium-sensitive crops; medium sodium hazard
Unsuitable	> 26	-----	Not recommended for irrigation due to severe sodium hazard.

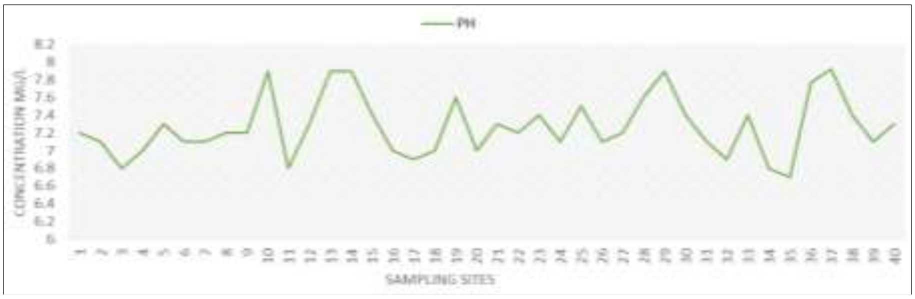

Fig 2: Variation in Ph

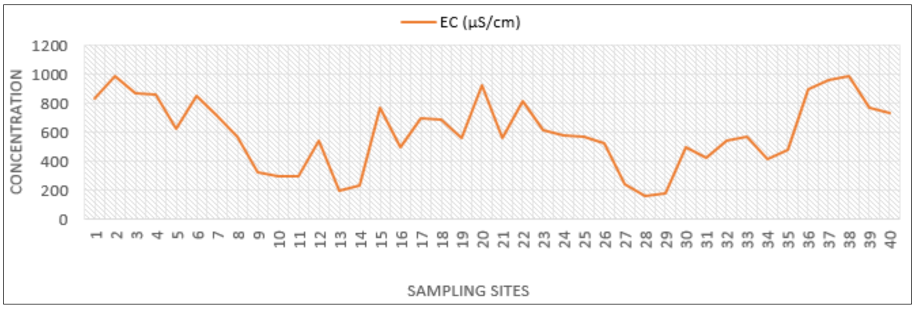

Fig 3: Variation in EC

Fig 4: Variation in TA, TH, and TDS

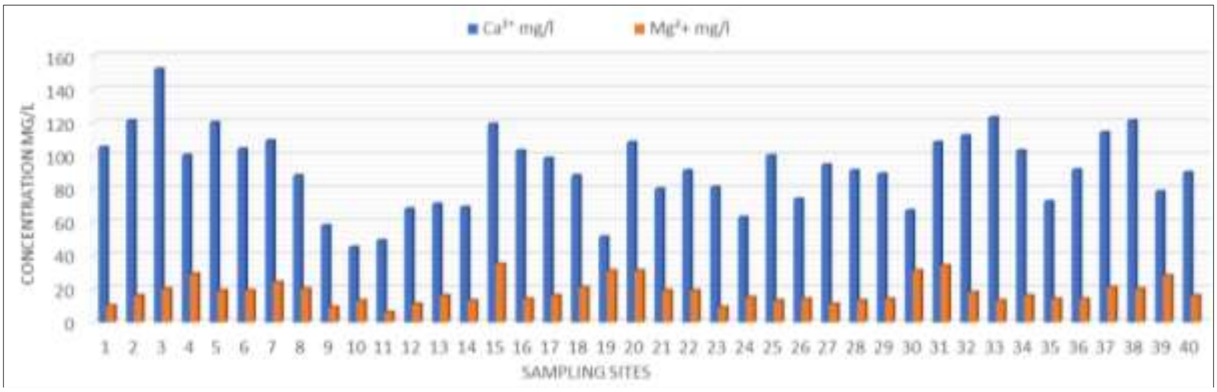

Fig 5: Variation in Ca and Mg

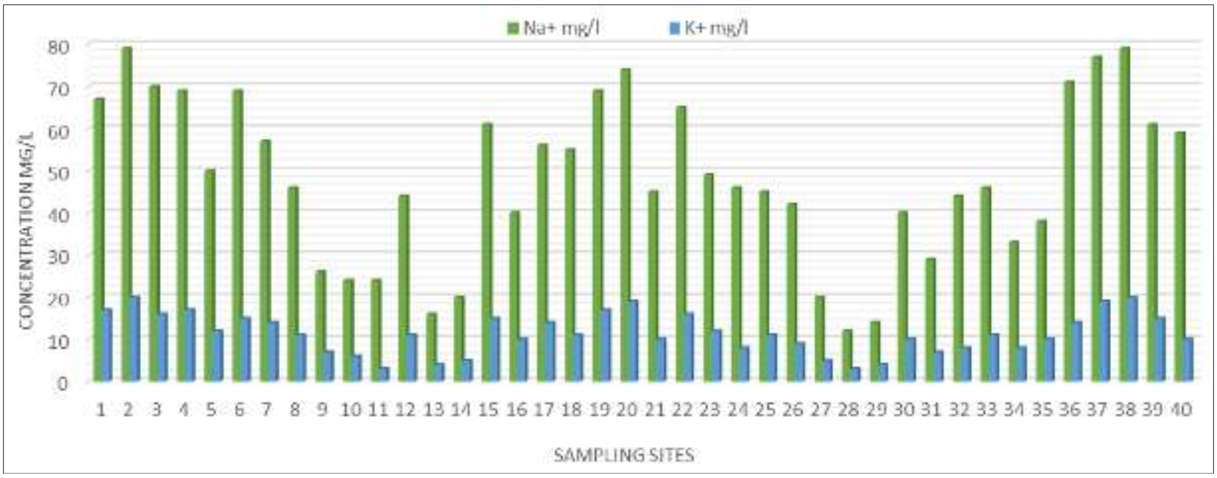

Fig 6: Variation in Na and K

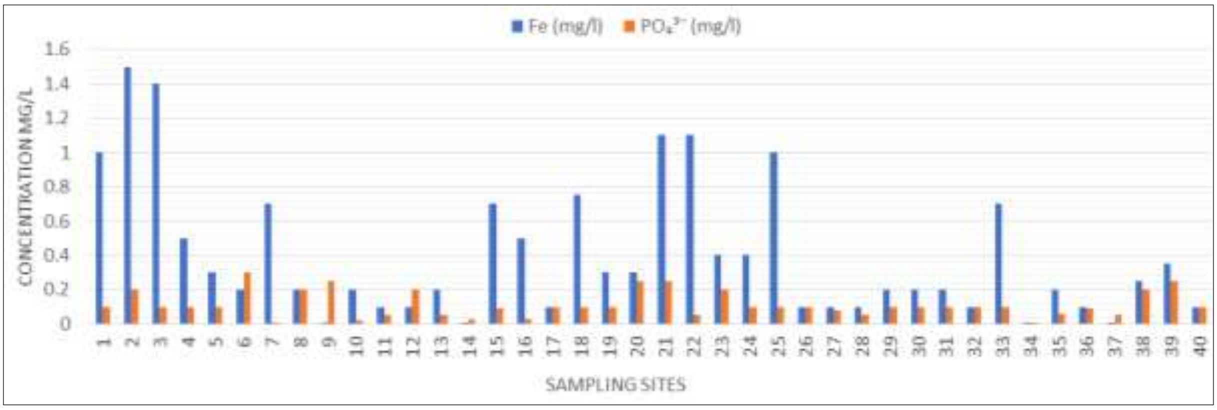

Fig 7: Variation in Iron and Phosphates

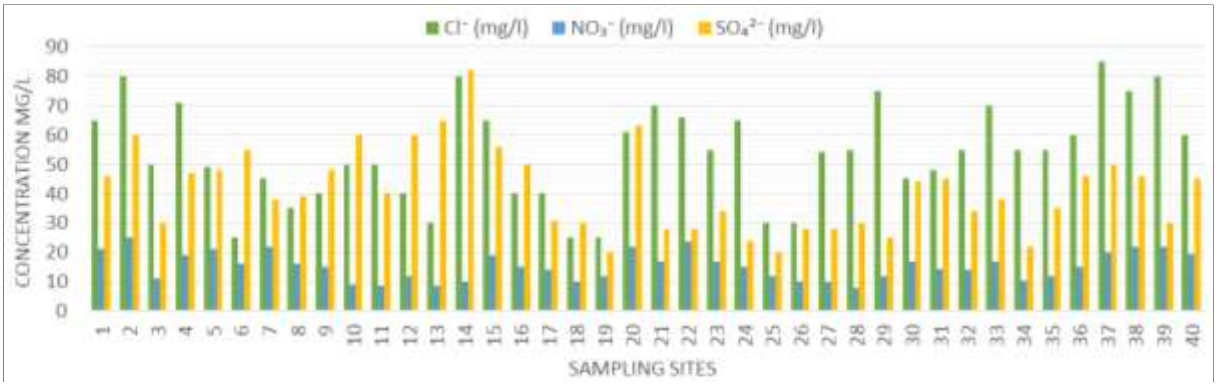

Fig 8: Variation in Chlorides, Nitrates, and Sulfates

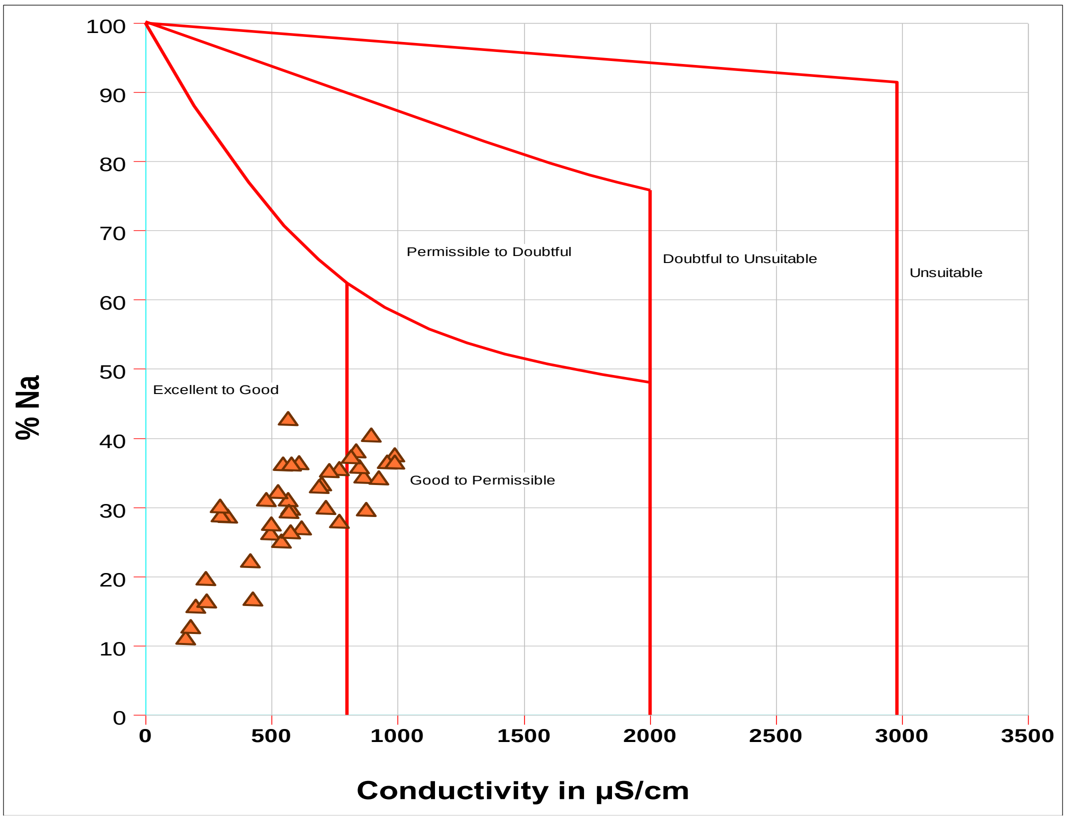

Fig 9: Wilcox diagram for %Na

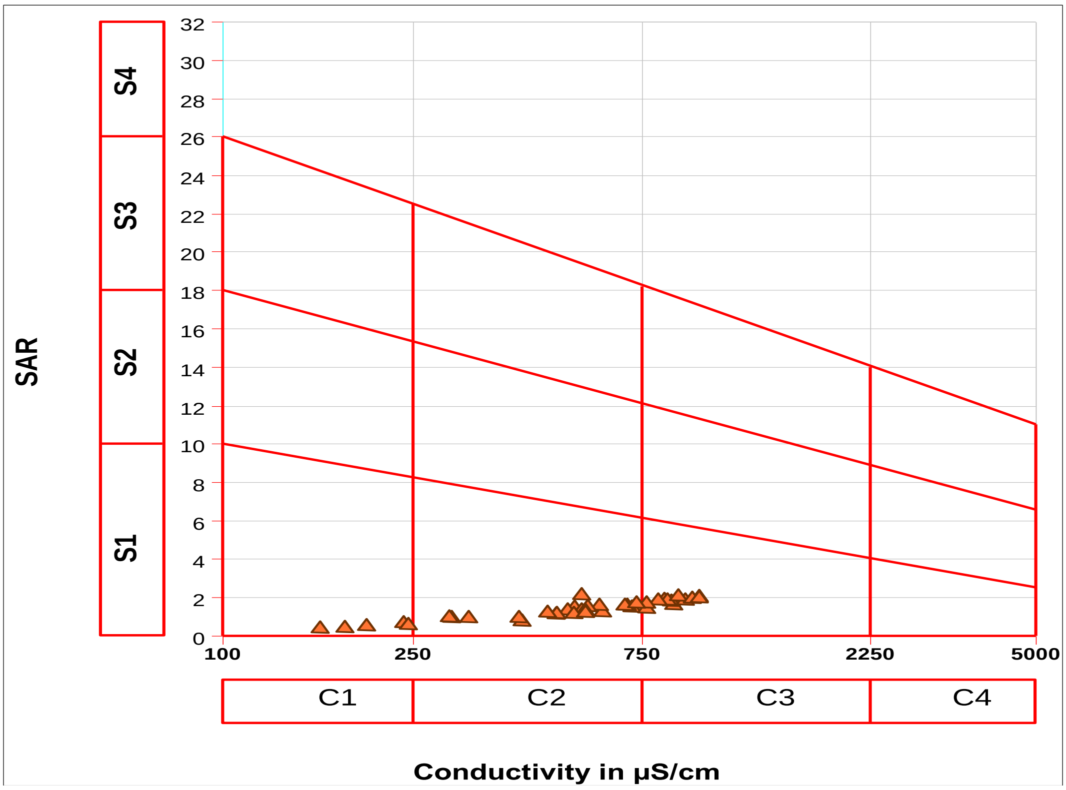

Fig 10: USSL Salinity Hazard Diagram

Conclusion

The objective of this study is to examine the hydrochemistry of groundwater in the Budgam district of Jammu and Kashmir. Through a comprehensive analysis of 40 samples collected from various locations within the study area, the physicochemical characteristics of the groundwater were found to be generally consistent with the regulatory standards set by WHO (2017) and BIS (2012). While the overall groundwater quality was satisfactory, localized instances of elevated total hardness and iron were observed, exceeding recommended limits at some locations. The groundwater exhibited a slightly alkaline pH, with electrical conductivity (EC) indicating mildly saline water suitable for diverse applications. Total alkalinity and total dissolved solids (TDS) remained within acceptable ranges. However, groundwater hardness varied from moderately hard to very hard, potentially necessitating treatment methods like ion exchange, reverse osmosis, or chemical precipitation for excessively hard water. Calcium and sodium were the dominant cations, followed by magnesium and potassium. Elevated iron concentrations, particularly in shallow wells, may require treatment through oxidation and filtration techniques, ion exchange, or greensand filtration. Additionally, Chloride and sulfate concentrations, predominantly from shallow depth wells, pose challenges, along with increasing nitrate levels warrant monitoring and potential mitigation strategies. The analysis of salinity hazard in irrigation water, based on specific conductance, reveals that the majority of groundwater samples in the research region are suitable for irrigation, falling into the low salinity class. This classification indicates that most samples can be used to irrigate various crops and soils. Additionally, the percent sodium (%Na) falls within acceptable ranges, with the majority of samples falling in excellent to good according to Wilcox's (1955) [27] and Eaton's (1950) [7] criteria. The Sodium Adsorption Ratio (SAR) values for all sample sites are less than 10, indicating excellent suitability for irrigation purposes. Overall, the groundwater quality in the region appears suitable for most purposes. However, implementing measures to address hard water and high iron content at certain locations and closely monitoring areas with high salinity levels would ensure sustainable water use for both domestic and agricultural needs.

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