20 Application of Environmental Isotopes and Hydrogeochemistry in Groundwater Management—A Case Study of Bringi Watershed, Kashmir Himalayas, India

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Abstract

Twenty-seven water samples including precipitation (3), streams (6) and springs (18) from Bringi watershed, southeast Kashmir were bimonthly collected for 1 year and analysed for ionic concentrations, stable isotopes and tritium. The objectives of the study were to recognize the site of recharge for Karst springs, components and mechanism of groundwater recharge. The local meteoric water line (LMWL) is $\delta D = 7.094 \times \delta^{18}O + 9.791$ ($r^2 = 0.82$) on the basis of monthly averages weighted amount. The winter precipitation isotopic composition (average = −10.4‰ for $\delta^{18}O$ and −58.2‰ for δD) is reflected in streams (average = −8.5‰ for $\delta^{18}O$ and −47.3‰ for δD) and spring water (average = −8.8‰ for $\delta^{18}O$ and −51.7‰ for δD) during summer and late spring, which is representative of winter snow melting. Mean elevation of recharge was estimated between 2500 and 2900 m above the mean sea level (amsl) using altitude effect ($\delta^{18}O$ = −0.27‰ per 100 m). Based on the isotopic mass balance equations, the average surface to groundwater contribution in peak flow time was 337.35 m^3/s, approximately 75% of total discharge from the stream and 7.5 m^3/s during lean period, which is approximately 18.6% of total runoff. In addition, average residence time of springs is very short (less than 1 year) and hence responds very quickly to the hydrological events. The quality of surface and groundwater is good for drinking, domestic and agricultural purposes.

Keywords

Bringi watershed kashmir · Environmental isotopes · Hydrogeochemistry · Karst springs · Recharge area

20.1 Introduction

Kashmir Valley is bestowed with adequate assets of water in variety of glaciers, snow, groundwater and surface water. Several springs of freshwater occur in southeast Kashmir, in Anantnag District (‘Ananta’ means infinite and ‘Naga’ means water springs) controlled by Karst terrain (Lawrence 1967; Bhat et al. 2014, 2019a; Alam et al. 2017). For decades, the springs are used for various purposes (i.e. drinking, agriculture, aquaculture, floriculture, tourism, etc.).

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For the flourishing of any socioeconomic culture, water resources which includes glaciers, lakes, groundwater are of immense importance (Singh et al. 2017; Kumar et al. 2020; Taloor et al. 2020a, b)

Among the upper land catchments of River Jhelum, Bringi catchment is a karst terrain with replacement of water between Karst springs and streams (Coward et al. 1972; Jeelani et al. 2011, 2014). To reduce contamination of water resources of the area, it is important to demarcate the potential sites of springs recharge and their recharging mechanism (Jeelani et al. 2014; Gat 1971; Ford and Williams 1989). Environmental isotopes (δ^2H, $\delta^{18}O$ and ^3H) along with hydrogeochemistry and hydrogeology have been used by several workers (Ford and Williams 1989; Eyankware et al. 2018). The isotopic signature of meteoric water at a particular location serves as a basis for demarcating ground water recharge area (Gat 1971; Lee et al. 1999; Gonfiantini et al. 1976; Jeelani et al. 2010; McConville et al. 2001). On the other hand, as a result of interaction between rock and water, the chemistry of groundwater changes until a quasi-chemical equilibrium is reached especially HCO_3, Ca and Mg (Goldscheider and Drew 2007; Adimalla and Taloor 2020a; Freeze and Cherry 1979; Jasrotia and Kumar 2014; Fetter 1980; Jeelani et al. 2010; Sah et al. 2017; Bisht et al. 2018; Jasrotia et al. 2018, 2019; Adimalla and Taloor 2020b; Adimalla et al. 2020; Sarkar et al. 2020).

20.2 Area of Study

Bringi catchment, an upland watershed of River Jhelum in Kashmir Valley, lies between 33°20′ to 33°45′N latitudes and 75°10′ to 75°30′E longitudes (Fig. 20.1), with an area of approximately 595 km^2 (Bhat and Jeelani 2018). The elevation of watershed ranges 1650 m amsl at Achabal to >4000 m amsl at Sinthan top. Bringi Stream and its tributaries especially east Bringi and west Bringi which joins with the Jhelum River near Anantnag are drained in this watershed (Bhat et al. 2014).

The area is characterized by temperate climate with four well-developed seasons (Jeelani et al. 2014) and monthly variation in the average temperature and precipitation from 1990 to 2009 is shown in Fig. 20.2 (Bhat and Jeelani 2018).

20.3 Geology and Hydrogeology

Geologically, the area is covered by permo-Triassic rocks especially Triassic Limestone and Panjal Traps. Recent alluvium and Karewa deposits occurs towards low-lying area (Fig. 20.3) (Alam et al. 2017, 2018). Panjal Volcanics and rocks of Upper Palaeozoic are present along the marginal parts of study area. Triassic Limestone is >1000 m high deposit with different layers of sandstone and shale (Bhat et al. 2019c, d). The Karewa deposits are fluviatile and lacustrine sediments that lie on top of Triassic limestone, with unconsolidated coarse to fine-grained sand, dark grey clays, light grey sands, varved clays, brown loam, marl, gravel, silt, lignite, etc. (Bhat et al. 2019c, d). The fluvial deposits contain boulders, gravel, sand, silt, clay, which represent active flood plain sediments (Jeelani et al. 2010; Taloor et al. 2019).

Three main springs, namely, Achabalnag, Kokernag and Kongamnag hosted by the Triassic Limestone and Karewa deposits were studied (Fig. 20.4a–c) during the present work (Jeelani et al. 2014; Bhat and Jeelani 2018). Achabalnag is a Karst spring at the base of Sosanwar Hills, where the water gushes out from two sites about 150 m apart, with one major outlet carrying about 80–90% of the total spring discharge (Fig. 20.4a). The water is channelled through the Achabal Garden and Villages downstream. Kokernag, a set of seven springs, is another major Karst spring where the water gushes out at various places (Fig. 20.4b). The water is channelled through the Kokernag garden and the villages downstream. At Kongamnag, water forms a pool, at bottom of the hill of limestone (Fig. 20.4c) and the water is drained downstream through villages. Kokernag and Achabal springs are cold (8 °C–14 °C) as compared to Kongamnag with temperature ranging from 14 °C to 19 °C. Higher temperature of Kongamnag spring might be due to deep motion of infiltrating water. Kokernag discharge

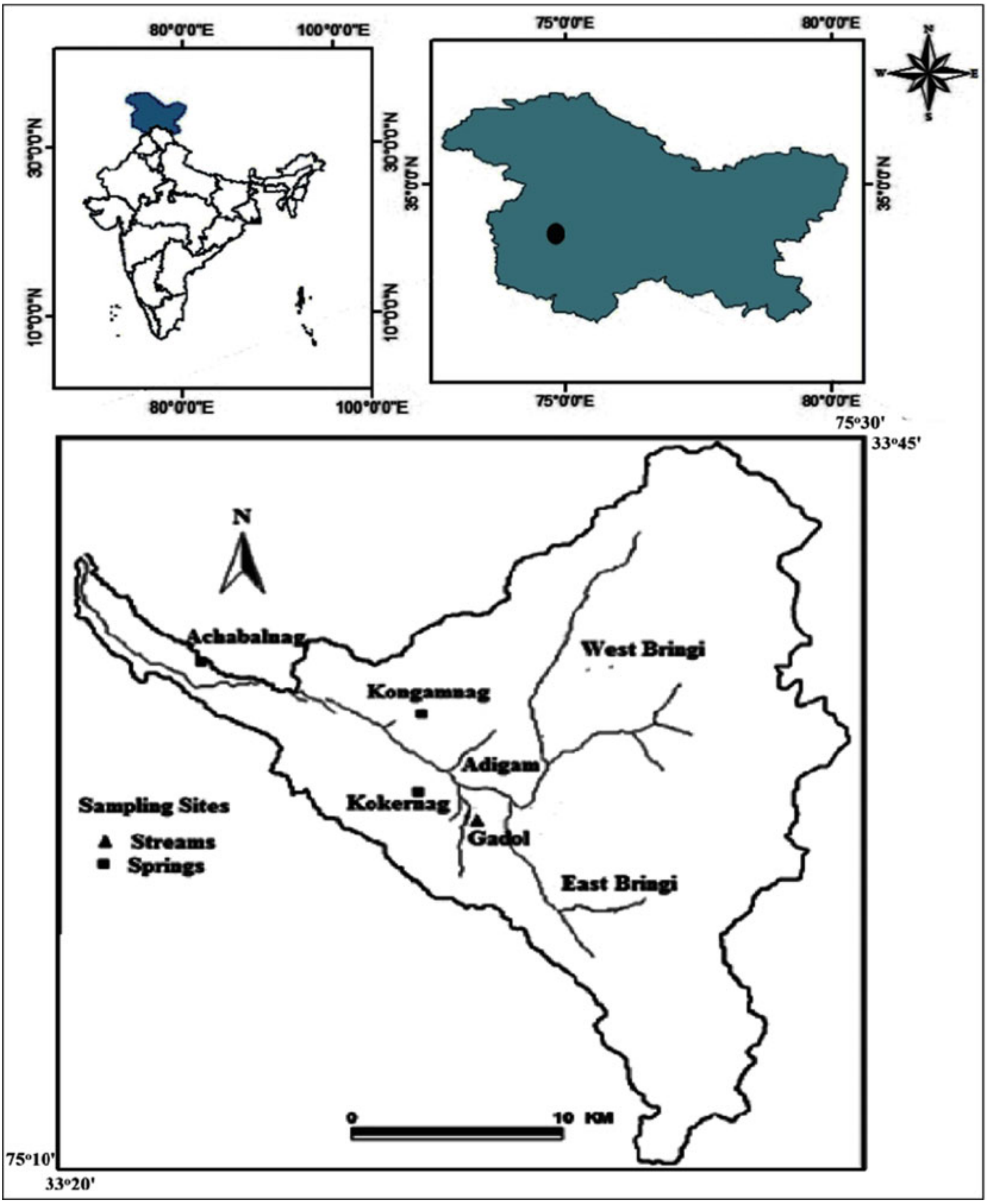

Fig. 20.1 Study area map with sampling sites (*Source* Bhat et al. 2014; Bhat and Jeelani 2018)

varies 600 L/s during winters to 8000 L/s during summers and Achabal discharge varies from 160 L/s in winter to 3000 L/s in summers. The variability in discharge is mainly due to fast response of spring to hydrological events. Discharge of Kongamnag varies 12L/s during winters to 20 L/s during spring and summer seasons.

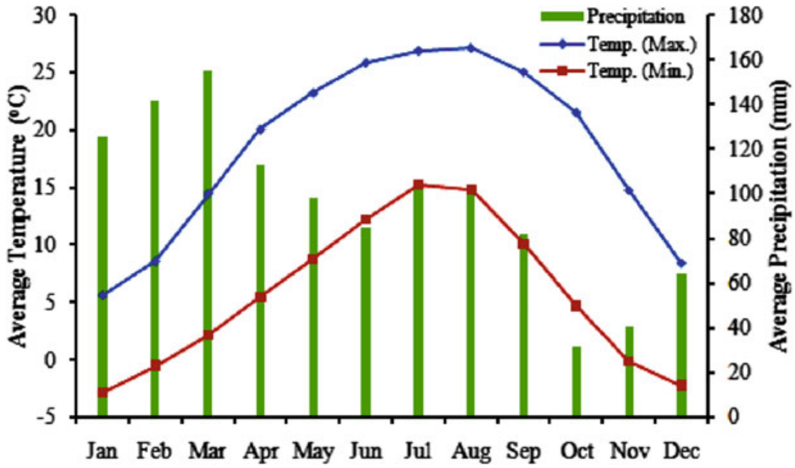

Fig. 20.2 Mean monthly precipitation and temperature from 1990 to 2009 (*Source* Bhat and Jeelani 2018)

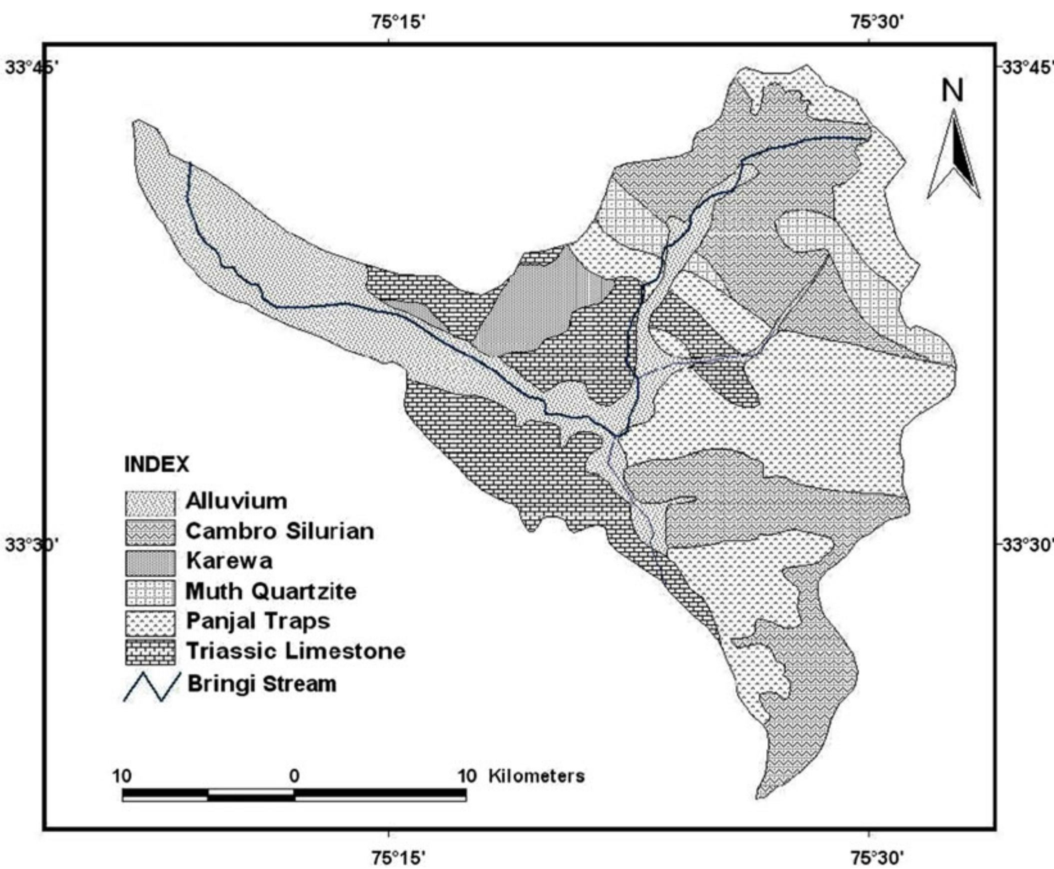

Fig. 20.3 Geological map of study site (*Source* Bhat et al. 2014)

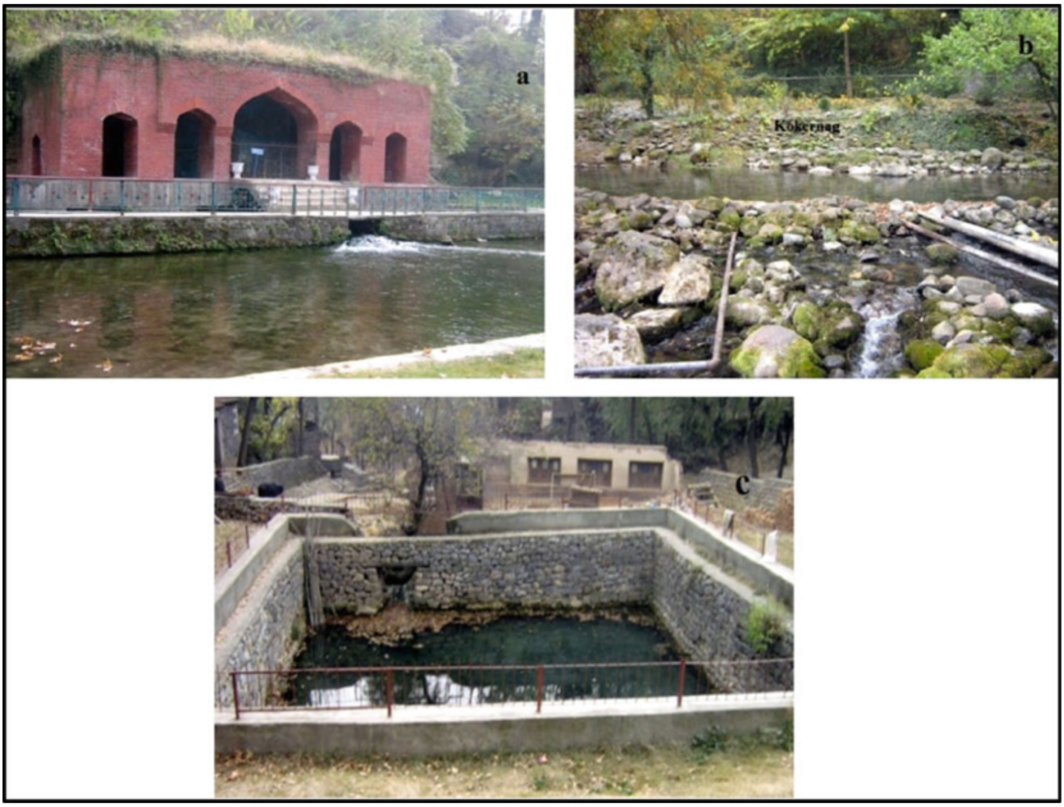

Fig. 20.4 Photgraphs of Bringi springs catchment **a** Achabalnag, **b** Kokernag and **c** Kongamnag (*Source* Authors)

20.4 Methodology

Water samples from Bringi Stream (two sites), three sites for precipitation (Pindabal, Kokernag and Achabal) and springs (Kokernag, Achabalnag, Kongamnag) were collected bimonthly for one hydrological cycle March 2008 to January 2009 (Fig. 20.1). The samples were analysed for ions including Na^+, Mg^{2+}, Ca^{2+}, K^+, Cl^-, HCO_3^-, SO_4^{-2}, SiO_2, F^-, NO_3^- and isotopes ($\delta^{18}O$, δ^2H and ^3H) by using the techniques (APHA 2006; Epstein and Mayeda 1953). Precipitation collectors were installed for collection of precipitation samples for stable isotopes. About 2 ml glycerine was added into the containers, which form a thin film above water to avoid evaporation. For ^3H analysis, the samples were collected in 1 litre sampling bottles during January to September 2008. Master parameters including pH, electric conductivity (EC) and temperature were measured in the field. Major ion analysis was carried out in Hydrogeology Laboratory, Department of Earth Science, Kashmir University, Srinagar. To separate the suspended sediments, waters were filtered through <0.45 μm nucleopore filter paper. All the cations and anions were calculated using the titration methods, flame photometer and spectrophotometer. The tritium and oxygen isotope analysis was carried out in Bhaba Atomic Research Centre (BARC) Mumbai whereas hydrogen isotope in NIH Roorkee (Epstein and Mayeda 1953). In addition, precipitation and temperature data were collected from IMD, Srinagar, Kokernag Station (Table 20.1).

Table 20.1 Bimonthly precipitation, temperature and discharge data of watershed Bringi

Stations	Parameters	Mar-08	May-08	Jul-08	Sep-08	Nov-08	Jan-09
Kokernag	Temperature (°C)	18.3	23.6	27.3	25.4	16.1	5
Kokernag	Precipitation (mm)	25.8	134.7	62.4	107	9.9	195
Pindabal	Stream discharge (m^3/s)	321	633	719	470	220	124
Adigam		95	170	266	133	58	57

(*Source* Bhat and Jeelani 2018)

20.5 Results

The statistical results of physicochemical parameters are given in Table 20.2 and isotope ($\delta^{18}O$, δD and ^3H) details are presented in Table 20.3.

20.5.1 Precipitation

The precipitation samples are moderately alkaline with pH varying from 8.6 to 8.9 with mean of 8.75. EC ranges from 64 to 78 µS/cm with average of 70 µS/cm. Total dissolved solids show a narrow range of salinity (41–50 mg/l) with mean of 46 mg/l. Ca (66%) is higher cation followed by Mg (21%) > Na (12%) > K (1%) and anions as HCO_3(83%) > SO_4 (10%) > Cl (7%). The concentration of different ions may be due to dissolution of various gases and atmospheric pollutants (Bhat and Jeelani 2015).

Stable isotopes in precipitation show marked spatial and temporal variations (Table 20.3). δD and $\delta^{18}O$ ranged from −12.59 to −60.6‰ with a mean value of −31.1‰ and −2.1 to −10.6‰ with a mean of –5.8‰. Samples were enriched during summer and low altitudes and depleted during winter and at higher elevation. Higher values were observed in July (δD = –12.6‰; $\delta^{18}O$ = −2.1‰) and lower in January (mean δD = −58.2‰, $\delta^{18}O$ = −10.4‰). Stable isotopes in precipitation showed good correlation (Fig. 20.5) with precipitation amount and temperature (r^2 = 0.97).

20.5.2 Streams

Temperature of the stream water samples varied from 9.6°C to 17.4°C with an average of 12.48 °C. pH between 7.8 and 9.8 with mean of 8.2 indicate stream water is alkaline. Electrical conductivity varied from 140 to 235 µS/cm, with mean value of 175 µS/cm. Similarly, TDS varied from 89 to 193 mg/l with average 122 mg/l. About 50% of samples show cation order as Ca (62%) > Na (21%) > Mg (13%) > K (4%) and anion order as HCO_3 (88%) > SO_4 (8%) > Cl (4%). Remaining 50% showed cation as Ca (61%) > Mg (26%) > Na (12%) > K (1%) and anion as HCO_3 (89%) > Cl (7%) > SO_4 (4%).

Stable isotopes of water collected from stream showed small variation (Table 20.3), with δD from −36.4 to −47.3‰ with average −44.1‰ and $\delta^{18}O$ ranging from −6.8 to −8.5‰ with average −7.8‰. Water is enriched in early autumn (September) season (δD = −36.43‰ and $\delta^{18}O$ = −6.8‰) and depleted in late spring (May) season (δ^2H = −47.33‰ and $\delta^{18}O$ = −8.5‰). The isotopic characteristic of summer precipitation (July) with enriched isotopes is not fully reflected in the streams (Fig. 20.5). However, the enriched signals of summer precipitation are clearly reflected in streams during autumn season. During winter, base flow is the main contributor to surface runoff due to low temperatures and negligible melting.

Table 20.2 Statistical overview of analytical results of different water samples of study area along with comparison with WHO and BIS standards

Sample type	Sampling date and number	Stat	pH	EC	Temp	TDS	SiO_2	F^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	Ca/Mg
				µS/cm	(°C)	mg/L				mmol/L							
Precipitation	Mar–Jul 2008, N = 3	Min.	NA	64.0	NA	41.0	NA	NA	1.38	0.10	0.04	0.01	0.0002	0.26	0.02	0.01	2.6
		Max.	NA	78.0	NA	50.0	NA	NA	1.73	0.14	0.05	0.03	0.0005	0.30	0.05	0.04	3.5
		Mean	NA	69.7	NA	44.5	NA	NA	1.55	0.12	0.04	0.02	0.0003	0.28	0.03	0.02	3.06
		St. Dev	NA	7.4	NA	4.2	NA	NA	0.17	0.02	0.00	0.01	0.0001	0.02	0.01	0.01	0.44
Streams	Mar-08 to Jan-09, N = 6	Min.	7.8	140	9	89	0.2	0.8	0.35	0.29	0.04	0.09	0.0002	0.69	0.03	0.01	2.01
		Max.	9.8	235	17.4	150.4	1.7	1.4	4.2	0.81	0.40	0.10	0.03	2.13	0.16	0.16	8.7
		Mean	8.3	174.7	12.4	110.7	1.2	1.0	1.61	0.42	0.15	0.10	0.02	1.12	0.07	0.06	3.96
		St. Dev	0.8	38.2	3.3	25.4	0.5	0.3	1.53	0.19	0.13	0.01	0.01	0.53	0.05	0.05	2.54
Springs	Mar-08, N = 3	Min.	7.1	200	10.9	128	1.04	0.83	0.65	0.51	0.18	0.09	0.0002	1.15	0.08	0.09	1.2
		Max.	7.6	530	13.1	339.2	1.6	0.9	3.18	0.96	0.80	0.57	0.0005	3.61	0.19	0.19	3.32
		Mean	7.3	314.0	11.7	201.0	1.3	0.85	2.0	0.69	0.41	0.30	0.0004	1.97	0.14	0.15	2.22
		St. Dev	0.3	187.2	1.2	119.8	0.3	0.04	1.27	0.24	0.34	0.25	0.0001	1.42	0.06	0.05	1.06
	May-08, N = 3	Min.	7.4	142	11.2	90.88	0.5	0.82	1.25	0.24	0.16	0.10	0.001	0.74	0.12	0.07	1.33
		Max.	8	442	13	282.8	0.7	0.86	4.2	0.92	0.48	0.52	0.003	2.79	0.13	0.17	2.00
		Mean	7.7	243.3	12.2	155.7	0.6	0.84	2.9	0.49	0.27	0.26	0.002	1.42	0.13	0.11	1.74
		St. Dev	0.3	172.1	0.9	110.1	0.1	0.02	1.5	0.37	0.18	0.23	0.005	1.18	0.01	0.05	0.36
	Jul-08, N = 3	Min.	7.2	236.0	10.4	151.0	0.5	0.82	1.2	0.55	0.16	0.09	0.001	1.56	0.04	0.01	0.98
		Max.	7.8	454.0	14.3	290.6	0.75	1.25	4.55	0.92	0.76	0.58	0.003	3.03	0.17	0.10	4.19
		Mean	7.4	338.7	12.8	216.7	0.6	1.09	3.06	0.74	0.38	0.27	0.002	2.24	0.11	0.04	2.88
		St. Dev	0.3	109.6	2.1	70.1	0.15	0.23	1.7	0.18	0.33	0.27	0.001	0.74	0.07	0.05	1.68
	Sep-08,	Min.	7.0	222.6	12.0	142.5	0.7	0.62	0.85	0.63	0.24	0.11	0.003	1.47	0.03	0.02	1.15

(continued)

Table 20.2 (continued)

Sample type	Sampling date and number	Stat	pH	EC	Temp	TDS	SiO_2	F^-	NO_3^-	Ca^{2+}	Mg^{2+}	Na^+	K^+	HCO_3^-	SO_4^{2-}	Cl^-	Ca/Mg
				μS/cm	(°C)	mg/L				mmol/L							
	N = 3	Max.	7.7	448.0	14.4		1.9			0.80	0.70		0.005	3.20	0.37		2.64
		Mean	7.3	319.7	13.4	204.6	1.2	0.65	3.4	0.71	0.41	0.32	0.004	2.13	0.18	0.10	2.07
		St. Dev	0.4	115.9	1.2	74.2	0.6	0.05	2.45	0.09	0.25	0.29	0.0009	0.93	0.17	0.12	0.81
	Nov-08, N = 3	Min.	7.3	212.2	11.9	135.8	0.6	0.74	0.72	0.34	0.36	0.13	0.002	1.23	0.10	0.04	0.94
		Max.	8.1	454.8	14.3	291.1	1.7	0.96	5.0	0.86	0.72	0.24	0.005	3.44	0.27	0.22	1.2
		Mean	7.6	305.7	13.3	195.7	1.0	0.85	3.34	0.57	0.50	0.19	0.0025	2.02	0.19	0.11	1.11
		St. Dev	0.4	130.5	1.2	83.5	0.6	0.11	2.29	0.27	0.19	0.06	0.001	1.23	0.09	0.10	0.14
	Jan-09, N = 3	Min.	7.6	280.2	8.2	179.3	0.17	0.86	0.68	0.81	0.34	0.11	0.004	1.97	0.03	0.04	1.38
		Max.	8.2	520.2	12.0	332.9	1.7	0.96	4.2	1.16	0.84	0.23	0.006	3.93	0.09	0.18	2.4
		Mean	7.9	367.5	9.7	235.2	0.7	0.9	2.89	0.93	0.53	0.17	0.005	2.68	0.06	0.09	1.93
		St. Dev	0.3	132.7	2.0	84.9	0.9	0.05	1.92	0.20	0.27	0.06	0.001	1.09	0.03	0.08	0.52
WHO 2006			7–8.5	–		–	–	1.5	45	1.875	1.233	8.7	0.307	–	2.08	5.64	–
BIS 2012			6.5–8.5	–		–	–	1.5	45	1.875	1.233	–	–	3.28	2.08	7.05	–

(*Source* Bhat et al. 2014)

Table 20.3 Statistical summary of isotopes ($\delta^{18}O$, δD and ^3H) in different water samples of Bringi Basin (AMSL—Above Mean Sea Level, Min—Minimum, Max—Maximum, Ave—Average, WM = Weighted Mean, Prec—Precipitation

Station	Sample type	Elevation (m AMSL)	$\delta^{18}O$ (‰)				δ^2H (‰)				Tritium (TU)
			Min	Max	Ave	WM	Min	Max	Ave	WM	
Achabal	Prec	1656	−10.0	−2.1	−4.8	−5.4	−60.6	−12.6	−26.2	−29.4	13.29
Kokernag	Prec	1890	−10.6	−2.4	−5.8	−6.2	−57.6	−23.2	−32.7	−35.0	14.65
Pindabal	Prec	2110	−10.4	−3.2	−6.6	−6.7	−56.5	−15.7	−34.4	−34.9	16.89
Bringi	Stream	2110	−8.7	−6.9	−7.9	−7.9	−47.3	−36.4	−44.1	−44.0	15.50
Achabal	Spring	1656	−8.6	−6.6	−7.8	−7.8	−47.3	−40.9	−44.0	−44.5	13.19
Kokernag	Spring	1890	−8.9	−7.2	−8.2	−8.2	−50.3	−40.7	−45.7	−45.8	15.48
Kongamnag	Spring	1922	−9.2	−8.1	−8.8	−8.9	−57.6	−54.6	−55.9	−55.8	16.65

(*Source* Bhat and Jeelani 2015)

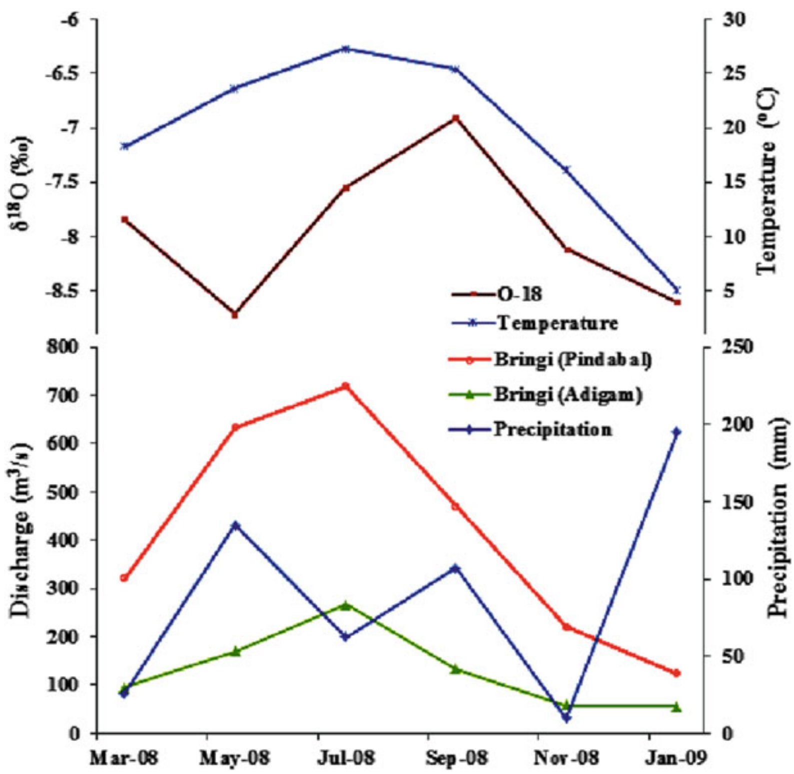

Fig. 20.5 Variation of $\delta^{18}O$, temperature, precipitation and stream discharge (*Source* Bhat and Jeelani 2018)

20.5.3 Springs

The water of springs is odourless and colourless. Water temperature varied from 8.2 °C to 14.4 °C with an average of 12.2 °C. The Karst springs including Kokernag and Achabalnag showed variability of annual temperature (~5.4 °C and ~3.8 °C) as compared to Kongamnag with annual inconsistency of 1.7 °C. The TDS varied between 90 and 339.2 mg/l, with average of 206 mg/l. Most of the samples show high Ca concentration than Mg while few show Na is higher than the Mg. While the anions showed high HCO_3 concentration.

The temporal and spatial variability of springs is given in Table 20.3, with δD ranging from −40.7 to −57.6‰ with average value of −48.5‰ and $\delta^{18}O$ ranging from −6.6 to −9.2‰ with a mean of −8.3‰. Achabalnag was enriched (average δD = −44.0‰; $\delta^{18}O$ = −7.8‰) and Kongamnag was depleted in heavy isotopes (average δD = −56.0‰; $\delta^{18}O$ = −8.8‰). The annual amplitude of $\delta^{18}O$ variations is 1.16 to 1.97, quite similar to the Karst springs of Meramec River Basin and Kapuz Karst springs (Kattan 1997; Fredrickson and Criss 1999) with amplitude varying from 1 to 2.

20.5.4 Tritium (^3H)

Tritium concentration of precipitation water varied from 13.3 to 16.9 TU and average 15.1 TU (Table 20.3). There is higher value of tritium in snow samples of winter season while less in summer season indicating different sources of precipitation (Jeelani et al. 2010).

20.6 Discussion

20.6.1 Geochemical Processes Controlling Chemistry of Water

To determine the evolution of water, ions are powerful tools (Eyankware et al. 2018; Bhat et al. 2016, 2019b, c, d). The hydrochemical data was plotted in Gibbs diagram (Fig. 20.6) to find out the source of sample which shows the rock dominance environment (Gibbs 1970).

Four hydrochemical water types were observed following the order of Ca–Mg–HCO3 > Ca–HCO_3 > Ca–Mg–Na–HCO_3 > Ca–Na–HCO_3 in Piper trilinear diagram (Piper 1994) (Fig. 20.7). The water types have resulted due to carbonate dissolution. The evolution of stream water is Ca–Mg–HCO_3 water type which is due to limited time for interaction between water and rock as well as easily carbonate mineral dissolution.

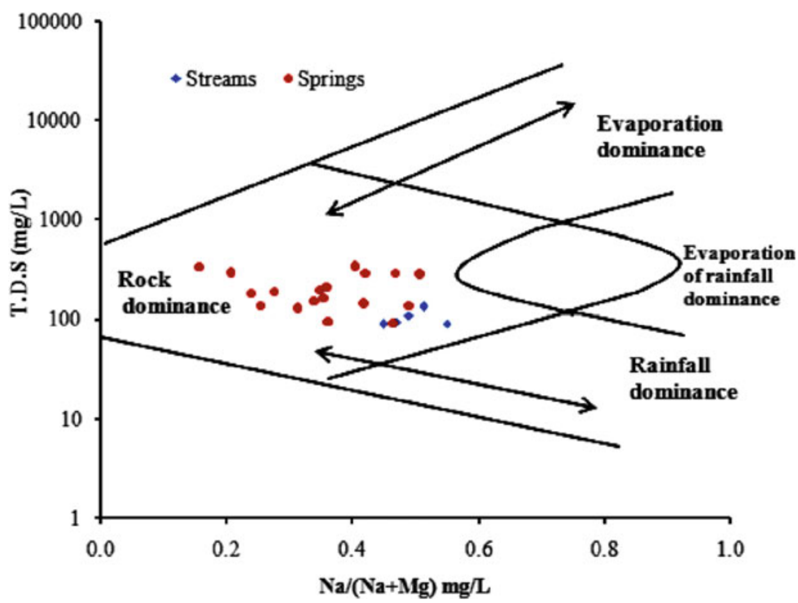

Fig. 20.6 Gibb's diagrams showing rock weathering as the main mechanism for groundwater evolution (*Source* Gibbs 1970; Bhat et al. 2014)

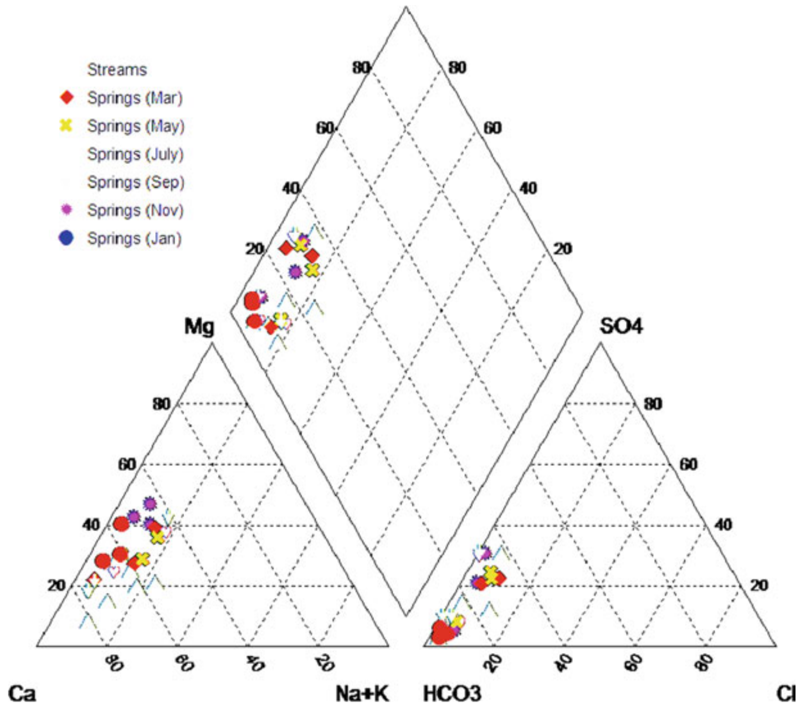

Fig. 20.7 Piper trilinear diagram showing carbonate weathering as the main mechanism for groundwater evolution (*Source* Piper 1994; Bhat et al. 2014)

The spring water and stream water are characterized by Ca–Mg–HCO_3 trend in Langelier–Ludwig diagram (Langelier and Ludwig 1942) which shows the clear dominance by carbonate dissolution (Fig. 20.8).

Various binary diagrams were plotted for identifying lithological source in water. In (Ca + Mg) versus HCO_3 (Fig. 20.9a), most water samples of stream lie on to the trend line, which shows carbonate weathering as the main source of solute acquisition. However, some spring water samples fall away from trendline indicating other source for HCO_3 in addition to carbonate weathering. In scatter graph between (Na + K) and (Ca + Mg) (Fig. 20.9b), the stream samples fall close to the trendline which might be because of silicate weathering. However, the spring samples especially Achabalnag and Kokernag fall away from trendline suggesting less contribution of ions from silicate weathering. In some spring samples (Kongamnag), (Na + K) exceeds (Ca + Mg) due to the impact of silicate weathering. In Cl^- and (Na + K) plot (Fig. 20.9c), all samples present above the trendline show different source of Na (Eyankware et al. 2018). The plots given in Fig. 20.9b, c favour the higher contribution of silicate weathering for ionic concentration, mainly Na.

The binary plot of Mg and Ca/Mg (Fig. 20.9 d) represents decrease in molar ratio with increase in Mg concentration, indicating weathering of carbonate rocks especially dolomite is main source for Mg and Ca. In Ca/(Ca + Mg) versus $SO_4/(SO_4 + HCO_3)$ binary plot (Fig. 20.9e), high Ca/(Ca + Mg) molar ratio is due to interaction of water with calcite. The Ca/(Ca + Mg) molar ratios of 0.5 and 1 correspond to dissolution of pure calcite and stoichiometric dolomite (Frondini 2008).

20.6.2 Delineation Area of Recharge for Karst Springs Using Hydrogeological and Hydrogeochemical Approach

The analytical results suggest that Bringi Stream and the Karst springs have similar chemical

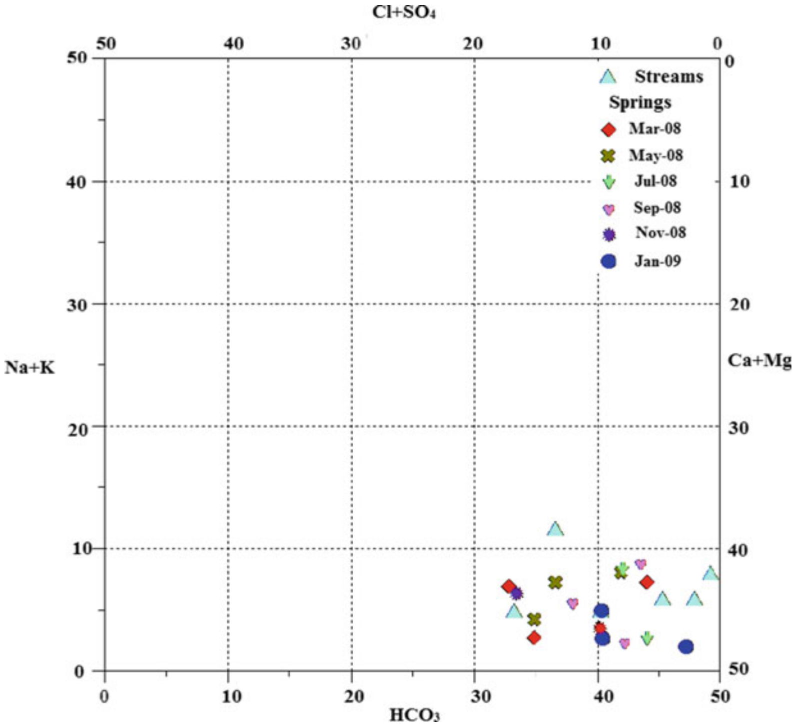

Fig. 20.8 Langelier–Ludwig diagram showing carbonate weathering as the main mechanism for groundwater evolution (*Source* Langelier–Ludwig 1942; Bhat et al. 2014)

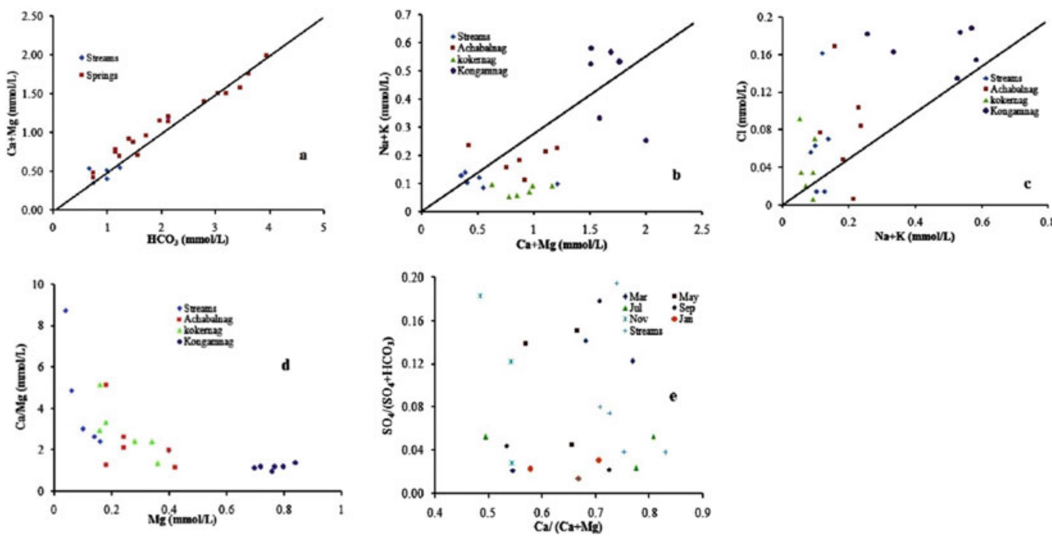

Fig. 20.9 Binary plots depicting ionic sources in streams and springs. **a** (Ca + Mg) versus HCO_3. **b** (Ca + Mg) versus Na + K. **c** (Na + K) versus Cl. **d** Ca/Mg versus Mg. **e** Ca/(Ca + Mg) versus SO_4/(SO_4 + HCO_3) (*Source* Bhat et al. 2014)

composition. However, a subtle difference between the major ion chemistry of the springs is observed. Kokernag and Achabalnag springs have low concentration of ions as compared to Kongamnag. This is mainly due to greater high contact time of water with base lithology in

Kongamnag as compared to Kokernag and Achabalnag springs. Both springs and streams show a different summer maximum and winter minimum temperatures (Jeelani 2010; Jeelani et al. 2014). Similarly, discharge of springs and streams is low during winter and high during summer (Fig. 20.10).

The temporal chemographs of Ca^{2+}, TDS and HCO_3^- of streams showed high concentration in January and March while low in remaining months (Fig. 20.11). In summer season, there is significant stream discharge and less interaction between water and rock, which decreases dissolved ion concentration in spring (dilution effect).

However, the Karst springs especially Achabalnag and Kokernag confirm high concentration in July, which is mainly because of piston effect. The temporal plot of spring discharge and TDS (Fig. 20.12) represents both TDS and discharge raise concurrently in July.

20.6.3 Isotopic Approach

The relationship among $\delta^{18}O$ and δD in global precipitation is known as global meteoric water line (GMWL) (Craig 1961) and is given in Eq. 20.1.

$$\delta D = 8 \times \delta^{18}O + 10 \quad (20.1)$$

Rozanski et al. (1993) modified the GMWL, using more available data (Eq. 20.2)

$$\delta D = (8.20 \pm 0.07) \times \delta^{18}O + (11.27 \pm 0.65) \quad (20.2)$$

Based on the amount weighed mean monthly samples, the regression equation between δD and $\delta^{18}O$ (Fig. 12.3) known as local meteoric water line (LMWL) is given in Eq. 20.3.

$$\delta D = 7.094 \times \delta^{18}O + 9.791 \left(r^2 = 0.82\right) \quad (20.3)$$

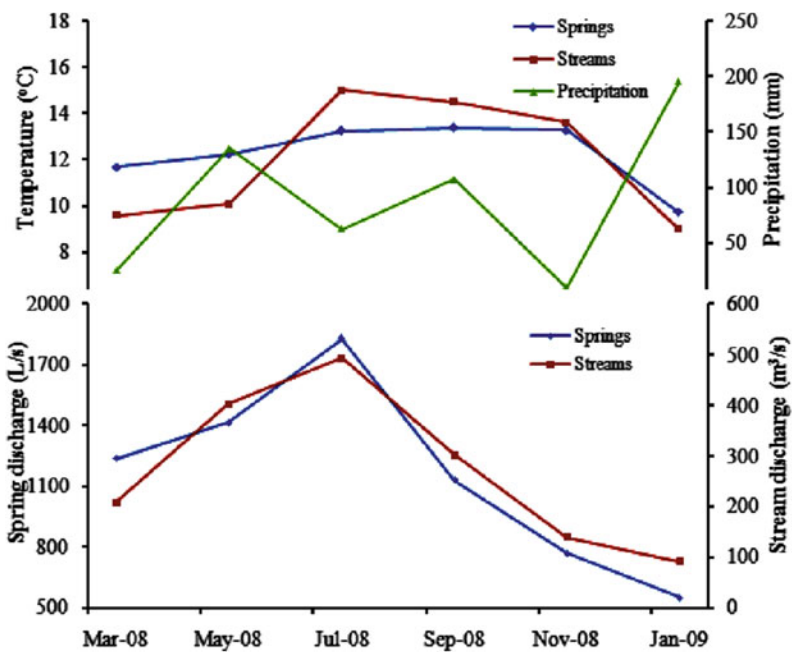

Fig. 20.10 Bimonthly variation of discharge, precipitation amount, stream and spring temperatures (*Source* Bhat et al. 2014)

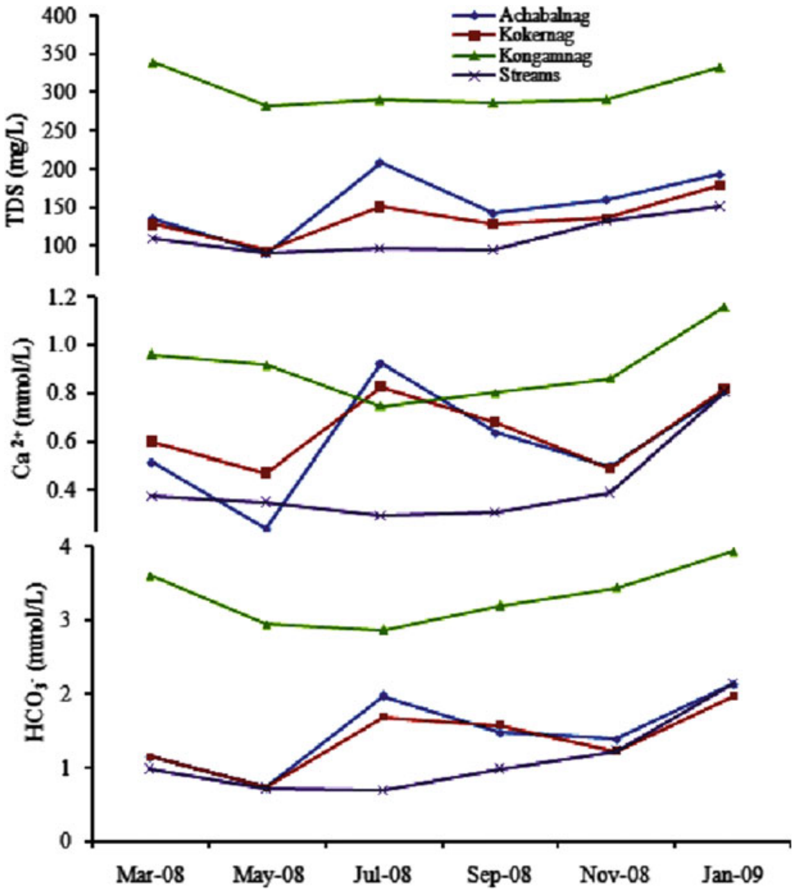

Fig. 20.11 Correlation of Ca, TDS, HCO_3 and chloride between Karst springs and Bringi Stream (*Scource* Bhat et al. 2014)

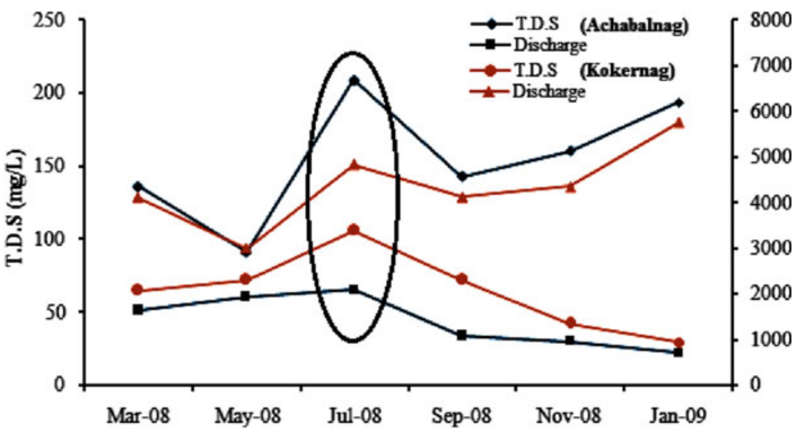

Fig. 20.12 Relationship of TDS with discharge of Achabalnag and Kokernag showing piston effect (*Source* Bhat et al. 2014)

The meteoric water line of study site is almost same as western Himalayas, $\delta D = 7.95 \times {}^{18}O + 11.51$ (Kumar et al. 2010). Shallower slope and low intercept than LMWL of western Himalayas and a shallow slope and high intercept to GMWL may be due to the different sources of moisture effect and/or effect of evaporation. Effect of temperature on the precipitation isotopic composition is observed in $\delta^{18}O$ versus δD plot (Fig. 20.13).

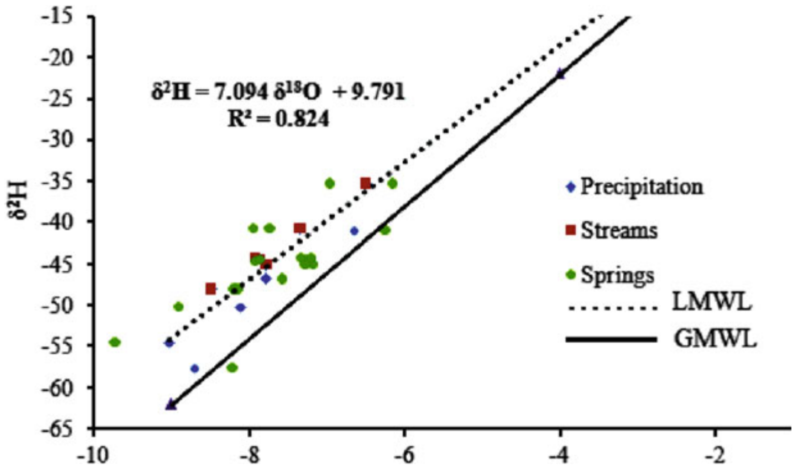

Fig. 20.13 $\delta^{18}O$ vs δD relationship of stream and spring water over GMWL and LMWL of Bringi watershed (*Source* Bhat and Jeelani 2015)

With increasing altitude the precipitation isotopic composition decreases, known as altitude effect (Ingraham and Taylor 1991), which is a significant tool to delineate the spring recharge areas (Jeelani et al. 2010). In the study area, altitude effect of −0.27‰ per 100 m was observed. The average elevation of area of spring recharge varies from 2500 to 2900 m amsl (Fig. 20.14).

There is a very good correlation (r^2 = 0.97) in seasonal $\delta^{18}O$ composition of streams and springs (Fig. 20.15), which indicates that the streams recharge these springs at different heights and share similar catchments.

20.7 Components and Mechanism of Groundwater Recharge

Various methods are present for defining the contribution of surface to groundwater. Chloride mass balance equation (CMBE) is used by a number of researchers to calculate the contribution of precipitation to groundwater (Bhat and Jeelani 2018).

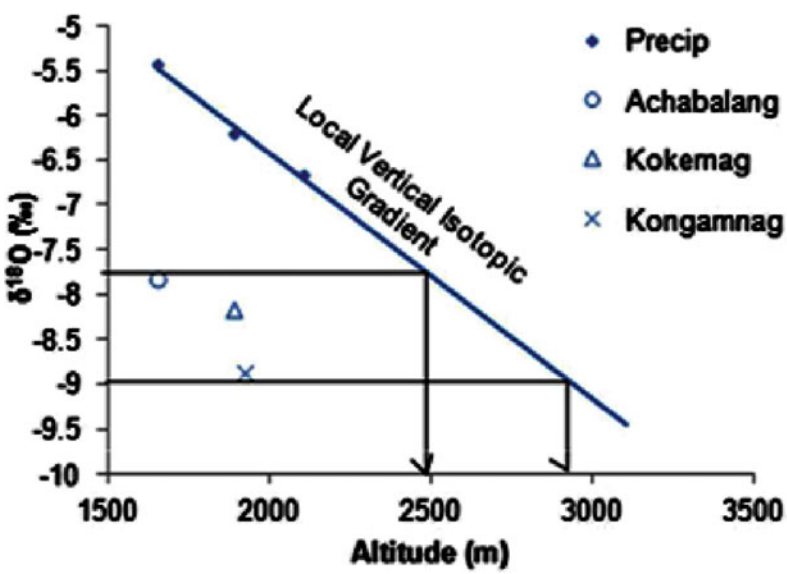

Fig. 20.14 The altitude versus $\delta^{18}O$, showing average elevation of spring recharge area (*Source* Bhat and Jeelani 2015)

$$\text{Recharge(mm)} = \text{Rainfall(mm)} * C_{\text{Rainfall}}/C_{\text{Spring water}} \quad (20.4)$$

where '*C*' is the concentration of chloride present in the precipitation and groundwater. The mean concentration of chloride of precipitation and springs is 0.57 mg/l and 3.55 mg/L. The estimated recharge through precipitation averages at 18.5%, with highest during July (about 22%) and lowest during November (<1%). Isotopic mass balance studies (IBME) defined that studies related to the isotopic mass balance indicate a mixture of two components (i.e. faction of groundwater (YG) and surface water (YS)

$$YS + YG = YM \quad (20.5)$$

$$YS\delta S + YG\delta G = YM\delta M \quad (20.6)$$

where YS and YG are the contribution of surface water and groundwater percentage to the mixture YM. δS, δG and δM are the isotopic composition of surface water, groundwater and admixture, respectively. Substituting Eqs. (20.5) in (20.6) for YG gives contribution of surface water component YS to the groundwater mixture.

$$YS = YM(\delta M - \delta G)/(\delta S - \delta G) \quad (20.7)$$

The mean $\delta^{18}O$ composition of surface water was −8.077‰ in high flow time (May to July 2008) and for groundwater before the high flow period (March 2008) is −8.19‰. The mean $\delta^{18}O$ composition for mixture of groundwater and surface water in September was −7.3‰. Therefore, the components of surface recharge during high flow period, 'YS', average at 337.35 m^3/s, about 75% of total stream discharge.

20.8 Residence Time of Groundwater

As determined by (Clark and Fritz 1997), the groundwater residence time by decay equation (Eq. 20.8) is

$$a_t^3H = a_o^3He^{-\lambda t} \quad (20.8)$$

where a_o^3H is the concentration in precipitation or initial tritium activity (expressed in TU) and a_t^3H concentration of tritium in groundwater or residual activity remains after decay over time *t*. As mean residence time of ground water is quite short (<1 year) in the study, it is short for Achabalnag and longer for Kongamnag. During the present investigation, dye testing was carried out near Adigam (Fig. 20.16a) and Gadol (Fig. 20.16b), which confirmed connection between recharge sites and Karst springs.

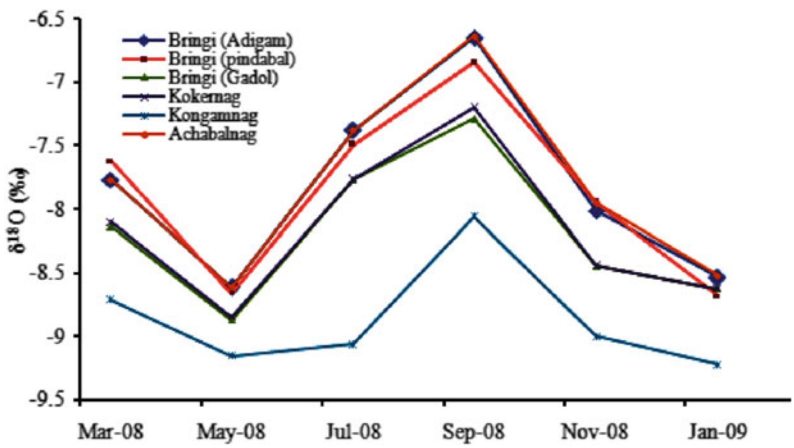

Fig. 20.15 Positive temporal variations of $\delta^{18}O$ of springs and streams of Bringi watershed (*Source* Bhat and Jeelani 2018)

Fig. 20.16 Dye testing carried out near **a** Adigam and **b** Gadol confirming connection between recharge sites and Karst springs (*Source* Authors)

20.9 Quality of Water for Drinking, Agricultural and Livestock Purposes

The water quality was carried out as per Bureau of Indian standards (BIS 2012) and World Health Organization (WHO 2011) for drinking (Table 20.1). The TDS of water samples is within the prescribed limits for the livestocks (Hamill and Bell 1986; Ravindra and Garg 2007). Based on the classification of hardness (Sawyer and McCarthy 1967), 45% samples are categorized under soft, 41.6% under moderately hard and 20.8% under very hard.

A number of plots and formulas are available for determining the suitability of water for purpose of irrigation. Wilcox diagram with specific conductance plotted against percentage Na is used for evaluating water for irrigation purposes (Wilcox 1955). The diagram shows that water is good for irrigation (Fig. 20.17).

Appropriateness of water for the purpose of irrigation can also be determined by plotting electrical conductivity (EC) against sodium absorption ratio (SAR) (Fig. 20.18) on the US Salinity Laboratory (USSL) diagram (Richards 1954). About 62.5% (15 samples) fall in C1S1 field of the diagram indicates low sodium/low salinity-type water and 37.5% (9 samples) belong to C2S1 category indicating good condition of water for irrigation for most soils and crops.

20.10 Conclusions

The results concluded t with following points:

- Ca^{2+} was the dominant cation and HCO_3^- was the dominant anion whereas four hydrochemical types of water have been identified as Ca–Mg–HCO_3 > Ca–HCO_3 > Ca–Mg–Na–HCO_3 > Ca–Na–HCO_3.
- Carbonate weathering is mainly responsible for ions in groundwater as inferred from scatterplots and hydrogeochemical.
- Hydrographs and chemographs for both springs and streams showed high Ca, TDS, EC and HCO_3 during winter and low during summer. The positive correlation of

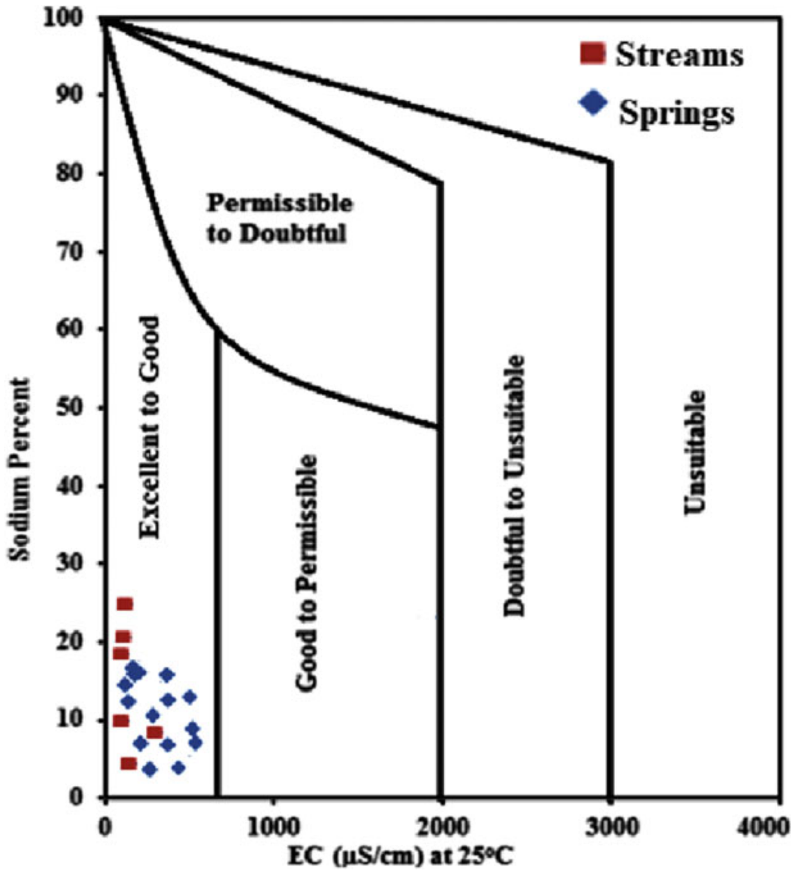

Fig. 20.17 Plot of electrical conductivity (EC) vs percent sodium (% Na) for water classification (*Source* Wilcox 1955)

chemographs of springs and streams indicates that Bringi Stream fed all the springs at various elevations.

- The LMWL for Bringi watershed is $\delta D = 7.094 \times \delta^{18}O + 9.791$ ($r^2 = 0.82$) whereas the springs are the major sources of recharge. The surface recharge component using IMBE averages at 337.35 m^3/s during high flow period, about 75% of total stream discharge and 7.5 m^3/s flow during low flow period, about 18.6% of total stream discharge.

20.11 Recommendations

Based on the present work, certain recommendations are made for preservation of the valuable water resource of the area.

- Fencing of the recharge sites near Adigam and Gadol is necessary to avoid contamination of water.
- Check dams may be built across Bringi Stream at Adigam Village and Gadol Stream near Gadol Village to maintain the flow of Karst springs during lean period.
- Continuous monitoring of water quality of streams and springs in terms of major and heavy metals. Continuous monitoring of stream and spring discharge to understand the response of springs to hydrological events.
- Public awareness programmes need to be conducted to create awareness among the people regarding the importance of preservation of the valuable resources of water of the area.

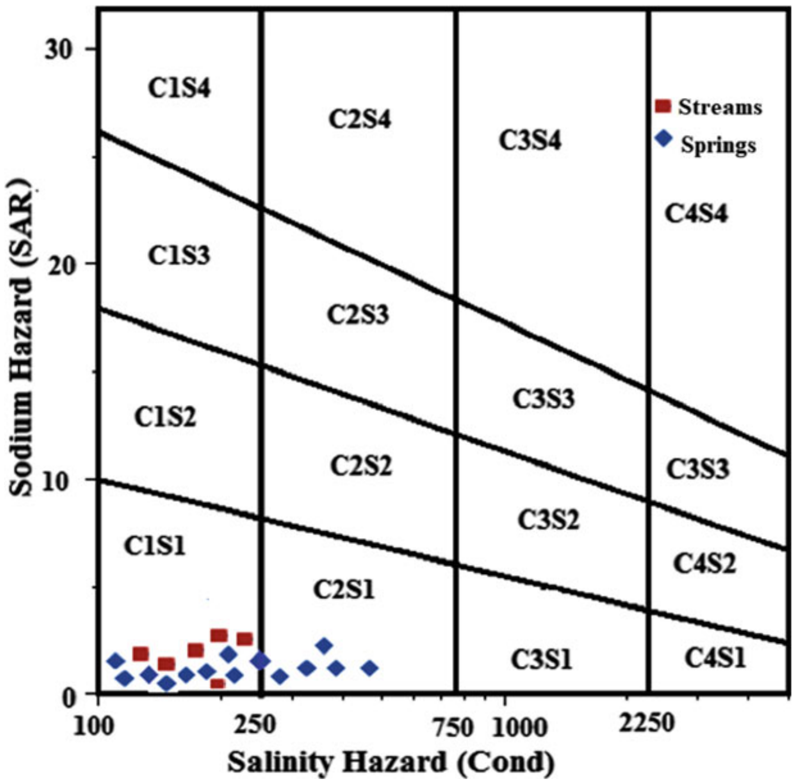

Fig. 20.18 Classification of water for irrigation purpose by using USSL Salinity Hazard Diagram (*Source* Richards 1954)

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