Hydrogeochemical assessment of River Jhelum and its tributaries for domestic and irrigation purposes, Kashmir valley, India

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Fifty water samples were collected during high flow (June 2008) and low flow (January 2009) periods from River Jhelum and its tributaries located in Kashmir valley, Western Himalaya, to carry out hydrogeochemical assessment for domestic, livestock and irrigation purposes. The high flow period represents the summer season, and the low flow period represents the winter season. In general, water was alkaline in nature. Ca^{2+} among the cationic budget, and HCO_3^- among the anionic budget, dominate the chemical quality of water. The higher annual average discharge (~1124.6 m^3/s) during high flow period resulted in lower ionic concentration in water through the effect of dilution than during the lower annual average discharge of ~406.4 m^3/s during low flow period. The water classification suggested the water to be of fresh category (100% <1000 mg/l TDS), which is therefore desirable for drinking purposes. Moreover, the mean values of major ions were within the permissible limits of WHO and ISI standards, suggesting that the water is suitable for domestic and livestock purposes. For irrigational practices, the calculated indices show that the water is of 'excellent to good quality'.

Keywords: Anionic and cationic budget, domestic and irrigation purposes, hydrogeochemical assessment, water quality.

RIVERS are complex systems of the flowing water draining their basins or watersheds, and provide an essential resource of water supply. Social, economic and political development is largely related to the availability and distribution of freshwater contained in the riverine systems. The river system characteristics depend on the size, form and geological characteristics of the basin and the climatic conditions which decide the quality of the water drained by the rivers[1]. A number of factors such as rock weathering, atmospheric precipitation, evaporation and crystallization influence the chemical quality of water[2]. The influence of geology on chemical quality of water is widely recognized[2,3]. Besides, anthropogenic activities such as domestic and agricultural practices also influence the water quality. Water pollution is one of the major causes which give rise to public health hazards. Poor water quality adversely affects plant growth, decreases agricultural production, increases investment in irrigation which, in turn, reduces agrarian economy and retards improvement in the living conditions of people. During last few decades, there is tremendous increase in the demand for freshwater due to rapid growth of population and industrialization. Therefore, water quality is rapidly declining worldwide, particularly in the developing countries[4,5]. In developing countries 1.8 million people, mostly children, die every year as a result of water-related diseases. About 80% of all the diseases in human beings are waterborne[6].

The present work is focused on studying the major ion chemistry and water quality of the River Jhelum and its tributaries in Kashmir valley, Western Himalaya, for domestic and irrigation purposes. For domestic purposes, the qualitative analysis of water is based on comparison of its hydrochemical characters with national (ISI) and international (WHO) water quality standards, whereas the irrigation quality was accounted based on several indices such as EC, %Na, sodium absorption ratio (SAR), residual sodium carbonate (RSC), magnesium absorption ratio (MAR), United States Department of Agriculture (USDA) classification, Kelly Index (KI) and permeability index (PI).

There are several reports of environmental studies on various water resources such as lakes[7,8], springs[9,10], groundwater[11,12], along with some studies on the main Jhelum River[13,14], based on a few samples and some studies on few major tributaries of the Jhelum (e.g. Lidder stream) in the Kashmir valley[15]. But, till date, a broad and comprehensive study, particularly on the hydrogeochemical nature of surface waters in the upper Jhelum and its tributaries is lacking. The present study will therefore contribute towards the hydrogeochemical knowledge of the River Jhelum and its tributaries in the Kashmir valley. The River Jhelum and its tributaries play an important role in socio-economic life of the people in Kashmir valley, as the river is the main freshwater resource for domestic, horticultural and agricultural purposes and hydropower generation. Besides, enormous agricultural

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activities are carried out on the floodplains of the River Jhelum and its tributaries. River Jhelum, after originating from the snow/ice-fed streams from the Great Himalayas and Pir-Panjal ranges and various springs of Anantnag district, drains the whole valley of Kashmir. Since during the last few decades, an increasing rate of construction, development of small-scale industrial units, increasing rate of transportation, human population, use of fertilizers and pesticides and other harmful substances have brought a drastic change in the quality of water in almost all water bodies of the valley, thereby posing a greater threat to life in the valley.

The Kashmir valley stretches between 34°17′–37°6′N lat. and 73°6′–80°30′E long. and is about 140 km long and 50 km wide. It is an elongated depression lying between the Greater Himalaya in the northeast and the Pir-Panjal range in the northwest. The basin covers an area of 33,670 sq. km and the length of the river is about 129 km. The river flows from Anantnag district through Khanabal, Bijebehara, Awantipora, Pampor, Srinagar, Pattan, Sopore and Baramulla before it enters the Pakistan territory at Kichhama (Baramulla). After joining the Wular Lake near Sopore, the river flows in a narrow gorge across the Pir-Panjal and turns towards south along a bend referred to as Synaxial bend[16]. The river is fed by a number of tributaries on both sides at different reaches, which are divided into two categories – right bank and left bank tributaries. The right bank tributaries include Sandrin, Bringi, Arapath (Kuthar), Liddar, Arapal, Sindh and Pohru. The Vishav, Doodganga, Sukhnag, Rambiara, Romshi and Ningal are the left bank tributaries (Figure 1). All along its course through the valley, the river water is polluted with heavy discharge of sewage and agricultural run-off received from catchment areas.

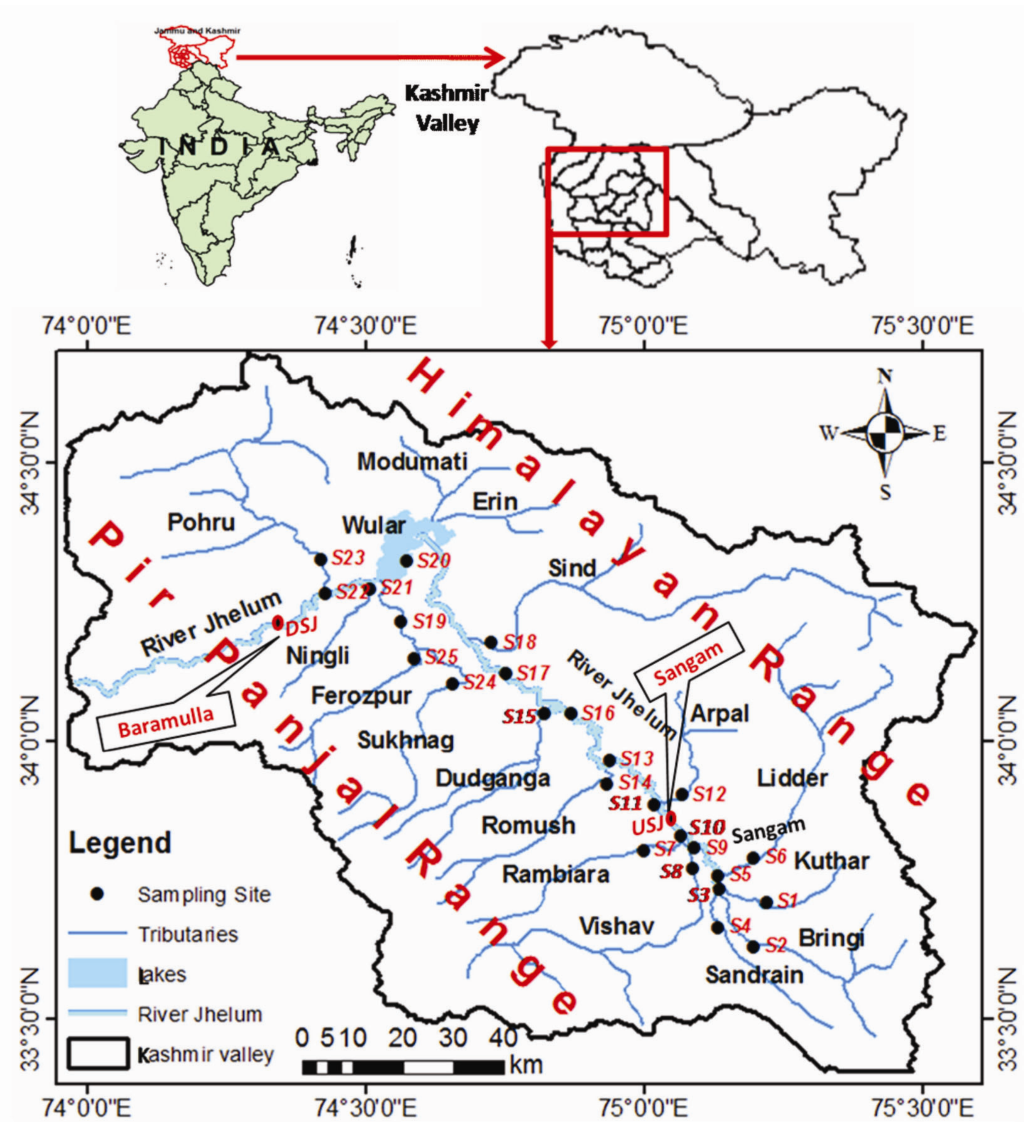

Figure 1. Location map of the study area. Site Upstream Jhelum (USJ) (Sangam in Anantnag) and Downstream Jhelum (DSJ) (Baramullla) represent the discharge measurement sites within the main Jhelum River.

Table 1. Summary of sampling sites

Sampling site	River/tributary	Location/village	Altitude (m amsl)	Catchment area (sq. km)	Discharge (m^3/s) in the upper catchment of	
					High flow (summer season)	Low flow (winter season)
S1	Kuthar (Arapat)	Bangidar (Khanabal)	1582	390	62.8	26.7
S2	Bringi	Bangidar	1586	665	57.0	30.3
S3	Jhelum(i)	Kursherpur (Khanabal)	1604	–	–	–
S4	Sandrin	Kureshpur	1599	291	90.7	14.7
S5	Jhelum(ii)	Gur (Khanabal)	1606	–	–	–
S6	Liddar	Gur	1613	1243	379.8	225.8
S7	Rambiara	Naiyan (Sangam)	1611	751	361.5	243.0
S8	Vishav	Naiyan	1611	985	367.7	323.3
S9	Jhelum(iii)	Sangam	1590	–	–	–
S10	Vishav	Sangam	1597	–	–	–
S11	Jhelum(iv)	Chursu (Awantipora)	1616	–	–	–
S12	Arapal	Chursu	1616	658	60.0	41.8
S13	Jhelum(v)	Kakapora	1583	–	–	–
S14	Romshi	Kakapora	1573	524	245.7	242.2
S15	Dudganga	Shaltang (Srinagar)	1604	700	336.2	98.7
S16	Jhelum(vi)	Ram Munshibagh	1555	–	–	–
S17	Jhelum(vii)	Shadipora	1522	–	–	–
S18	Sindh	Shadipora	1523	1526	1396.7	624.5
S19	Haritar	Haritar (Sopore)	1579	–	–	–
S20	Jhelum(viii)	Ningal (Sopore)	1584	–	–	–
S21	Ningal	Ningal	1584	613	58.2	19.0
S22	Jhelum(ix)	Daubgau (Sopore)	1574	–	–	–
S23	Pohru	Daubgam	1575	1927	151.0	67.3
S24	Sukhnag	Singpora (Patan)	1590	648	316.7	263.5
S25	Ferozpor	Palhalan (Patan)	1585	355	313.2	167.3
USJ	Jhelum*	Sangam	1595	–	2974.5	1179.3
DSJ	Jhelum*	Baramullah	1565	12,372	6507.5	1866.2

*Reflects the discharge measurement of main stream of River Jhelum at Sangam located upstream of Jhelum represented by site code USJ and Baramulla located at downstream of Jhelum represented by site code DSJ.

The river flows throw the vast track of the valley with varied topography and geology. The high structural hills, small mounds of Karewas, colluvial fan below the hill slopes and the alluvial-filled valley represents the geomorphology of the area. The basin geology is dominated by volcanics, limestone, quartzite, sandstone, shale, slates, fluvio-lacustrine deposits and alluvium. The basin is characterized by temperate climate with a mean annual rainfall of about 1100 mm. However, precipitation has a peculiar distribution pattern throughout the year. March receives maximum precipitation, October least and September–November is usually dry season.

In order to clearly understand the chemical nature of water and factors controlling its chemical quality, seasonal sampling was carried out. In the present study, the high flow period represents the summer season and the low flow period represents the winter season. A total of 50 water samples were collected which include 25 samples during high (June 2008) and low flow (January 2009) periods. The samples were collected in 1 litre polyethylene bottles at 25 sites of River Jhelum and its tributaries (Table 1). Prior to sample collection, the sample bottles were cleaned with conc. HNO_3, followed by complete washing with distilled water. Furthermore, the bottles were rinsed thoroughly with sample water prior to its collection. One sample was collected from the main stream of the River Jhelum before joining the tributary and another sample from the tributary before it enters the main river at their confluence point. The sample was taken from a depth greater than 15 cm below the water surface, to avoid contamination of floating debris. The water temperature, pH and conductivity were measured *in situ* using potable water analysis kit. The samples were filtered on spot through <0.45 μm Millipore membrane filters to separate the suspended sediments. Water samples were analysed using standard methods[17,18], in the Hydrogeochemistry Laboratory, Department of Earth Sciences, University of Kashmir, Srinagar. Hardness was determined by EDTA titration using ammonium buffer solution and Erichrome black T as indicator. Ca^{2+} and Mg^{2+} were determined by EDTA titration using murexide as indicator, whereas Cl^- ion was determined by titrating the samples against $AgNO_3$ (0.02 N) using potassium chromate (5%) as indicator. The HCO_3^- analysis was done by titration of the sample against HCl (0.01N) using methyl orange as indicator. The Na^+ and K^+ ions were determined by flame emission photometry. Spectrophotometer method was used for the determination of SO_4^{2-}, F^-, SiO_2 and NO_3^-.

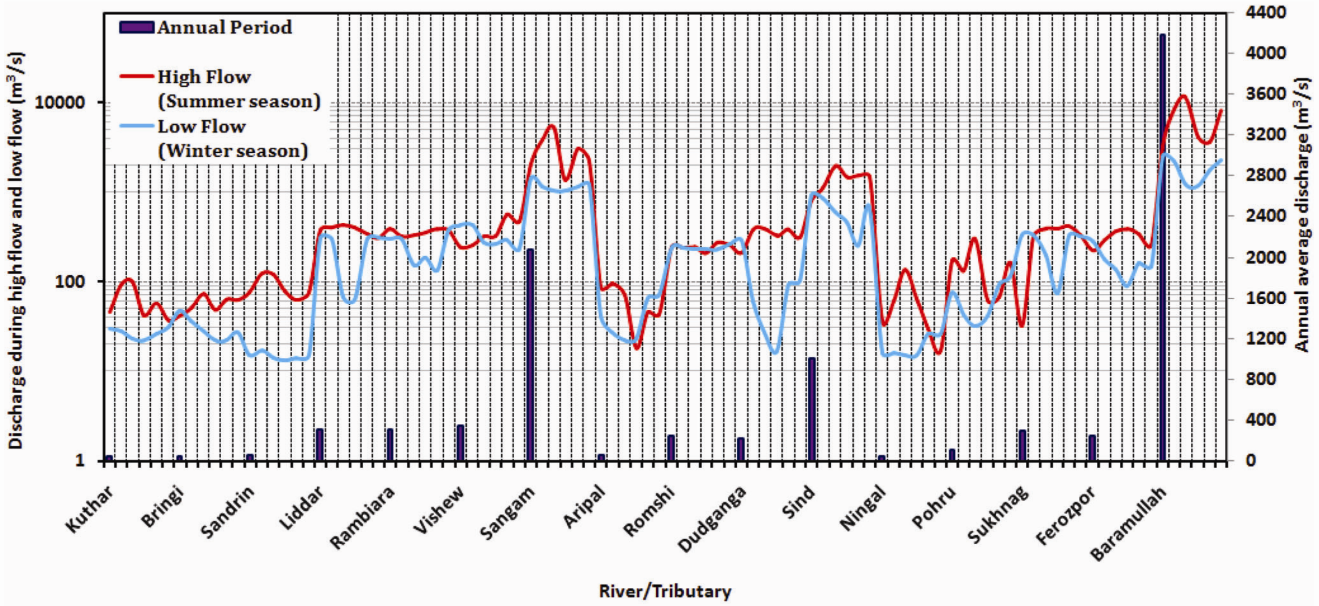

Figure 2. Comparison of monthly variation in discharge during high and low flow periods of River Jhelum and its tributaries. The values are plotted on a logarithmic scale of primary *Y*-axis. The average annual discharge is also shown and values are plotted on normal scale of secondary *Y*-axis.

River hydrology

In order to understand the seasonal distribution and variation of discharge of River Jhelum and its tributaries, the daily discharge data were procured from the Irrigation and Flood Control Department, Srinagar for 2008 and 2009, followed by calculation of an average value of monthly discharge for each year. It is pertinent to mention here that since the water sampling was carried out during June 2008 and January 2009, the discharge data from March 2008 to February 2009 were utilized for further analysis. An average value of discharge of seven months, i.e. March to September (MAMJJAS) for high flow period (summer season) and five months, i.e. October to February (ONDJF) for low flow period (winter season) was calculated for Jhelum River at two sites (USJ and DSJ) and its tributaries at all sites (Figure 1). The discharge varied from 57.0 m^3/s at S2 (Bringi) to 6507.5 m^3/s at DSJ (Jhelum) with an average of 1124.6 m^3/s during high flow period, whereas it varied from 14.7 m^3/s at S4 (Sandrin) to 1866.2 m^3/s at DSJ (Jhelum) with an average of 406.4 m^3/s. The analysis of average values of monthly discharge at each site showed 3–5 times higher discharge during high flow period than low flow period (Figure 2 and Table 1). As seen in the figure, there occurs a highest peak at Baramulla site (DSJ) with two subsidiary high peaks, one at Sangam (USJ) and another at Sindh (S18). The high peak at site USJ is due to the contribution of combined discharge of several major (6) and minor tributaries joining the River Jhelum above this site upstream whereas the highest peak at site DSJ is due to the overall influx of total discharge of all the upstream major (18) and minor tributaries joining the main Jhelum River. The site DSJ (Baramulla) is located at the outlet of the upper Jhelum basin. Streams such as Vishev, Rambiara, Liddar, Romshi, Dudganga, Sukhnag and Ferozpor show moderately high discharge due to contribution of melt water from snow and glaciers present in their catchment areas. However, the large catchment area of S18 (Sind) is highly glaciated, resulting in a high peak of its discharge[19]. The snowpack accumulated during preceding winter starts thawing due to smooth rise in ambient temperature in spring and summer season from March to September supplemented by monsoon rainfall, which results in enhanced flow in the River Jhelum and its tributaries during high flow period (R. A. Mir, 2009, unpublished). The contribution of snow to the run-off of the major rivers in Western Himalaya, of which Kashmir Himalayas is a part, is reported to be more than 60% (ref. 20). The summer season in Kashmir valley is also the period of peak agricultural activities due to availability of large amount of water and moderately high temperature feasible for crop cultivation which leads to discharge of huge amounts of agricultural waste such as fertilizers, manure, etc., into the Jhelum and its tributaries. On the other hand, the discharge remains low in the low flow period (winter season) because most of the precipitation occurring dominantly as snowfall freezes in the upper reaches due to the lower air temperature from October to February. The flow of River Jhelum and its tributaries in this period is mainly controlled by base flow.

Hydrogeochemistry

The statistical overview of hydrochemical parameters of water of the study area for two periods is presented in

Table 2. Statistical overview and comparison of physico-chemical parameters of River Jhelum and its tributaries for two seasons (high and low flow periods) with permissible water quality limits

	High flow (summer season)					Low flow (winter season)					WHO[6]		ISI[34]	
Parameters	Range	Mean	Median	Standard deviation	Coefficient of variance	Range	Mean	Median	Standard deviation	Coefficient of variance	Acceptable level	Maximum permissible level	Acceptable level	Maximum permissible level
Temperature (°C)	13.8–23.2	18.8	18.6	2.5	13.4	3.7–9.8	6.7	6.6	1.7	25.2	–	–	–	–
pH	7.5–8	7.6	7.7	0.1	1.6	7.5–8.4	7.9	8.1	0.2	3.0	7–8.5	6.5–9.2	6.5–9.2	9.2
Conductivity (μS/cm)	121–291	198.4	195.0	42.7	21.4	149.1–430	289.5	246.0	66.8	25.3	–	1600	800	4800
TDS (mg/l)	77–187	129.7	127.0	29.6	22.7	95.4–275.2	185	157.4	42.8	25.4	500	1500	500	3000
Total hardness (mg/l)	90–196	132.1	130.0	28.0	21.4	75–158	116	105.0	17.9	16.7	100	500	300	600
Ca^{2+} (mg/l)	23–45	32.6	31.0	6.0	18.3	25–44	34.5	34.0	5.2	15.0	75	200	75	200
Mg^{2+} (mg/l)	4.3–22.8	11.1	10.2	5.2	46.8	4.10–23.9	14.1	11.7	4.8	40.0	<30 (if SO_4 is 250 mg/l)	150 (if SO_4 is 250 mg/l)	30	100
Na^+ (mg/l)	6.3–13.4	9.1	8.6	1.8	20.6	6.4–15	10.7	9.5	1.9	19.6	–	200	–	–
K^+ (mg/l)	0.24–1.1	0.39	0.4	0.2	51.5	0.14–0.87	0.5	0.4	0.2	41.5	–	12	–	–
HCO_3^- (mg/l)	115–225	157.2	155.0	28.2	18.1	120–225	172.5	165.0	25.7	15.2	–	–	–	–
Cl^- (mg/l)	3.6–9	6.1	6.0	1.5	25.1	1.7–10.7	6.2	4.8	1.7	33.9	200	250	250	1000
SO_4^{2-} (mg/l)	1–16.8	6.8	6.1	4.6	65.3	1.1–50.3	25.7	7.0	6.6	77.5	200	400	150	400
SiO_2 (mg/l)	1.8–9.4	5.7	6.0	1.6	28.8	14.5–19.2	16.6	16.6	1.0	6.1	–	–	–	–
NO_3^- (mg/l)	6.8–14.0	9.1	9.0	1.4	15.1	3.5–6.5	5	5.2	0.9	17.1	–	50	45	–
F^- (mg/l)	0.90–1.1	0.9	0.9	0.1	13.3	0.62–0.93	0.7	0.8	0.1	11.0	–	1.5	–	–
NICB	–	1.05	–	–	–	–	0.53	–	–	–	–	–	–	–

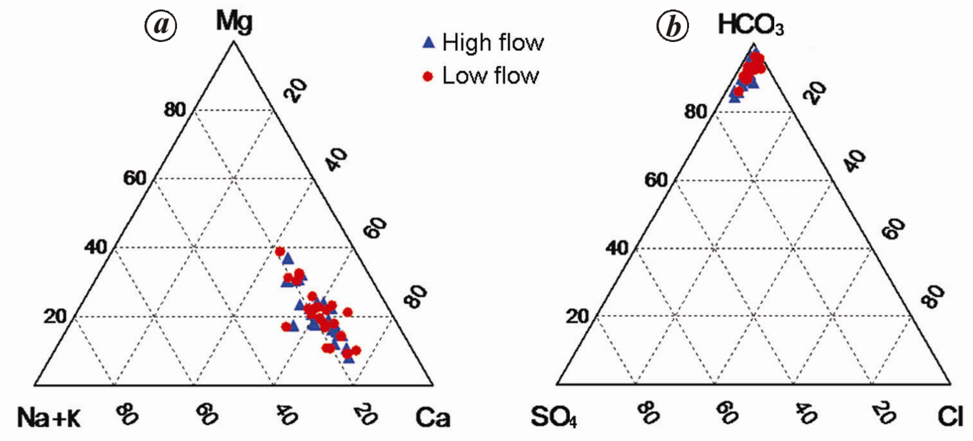

Figure 3. Ternary cation (***a***) and anion (***b***) plots for high and low flow periods showing the relative abundances of cations (Ca–Na+K–Mg) as well as anions (HCO_3–Cl–SO_4).

Table 2. The total cations ($TZ^+ = Na^+ + K^+ + Mg^{2+} + Ca^{2+}$) and total anions ($TZ^- = Cl^- + 2SO_4^{2-} + HCO_3^-$) were within <4% of the normalized charge balance ($NICB = \sum^+\sum^-/\sum^+$) for both the periods (Table 2). The SO_4^{2-}, Mg^{2+} and K^+ ions exhibit high variability with high coefficient of variation during both periods (Table 2). This variability of SO_4^{2-} is attributed to the weathering of carbonates, sulphide minerals such as gypsum and pyrite, and increased use of fertilizers. Mg^{2+} may be released from weathering of diverse lithology in the catchment area, whereas K^+ reflects the effect of pollution from domestic waste and role of decomposed plant matter[21]. The analytical results show that the temperature varies from 3.7°C to 23.2°C with an average of 12.8°C and exhibit clear seasonal variation. The pH suggests alkaline nature of water with values varying from 7.5 to 8.4 with a mean value of 7.9, reflecting the importance of the dissolution of limestone and dolomite-rich lithology in the drainage basin liberating Ca^{2+}, Mg^{2+} and aluminosilicates into the solution[22,23]. Electrical conductivity (EC) ranges from 121 to 430 µs/cm with a mean value of 76 µs/cm. The higher EC was attributed to the accumulation of dissolved solids from the upland areas by rainwater and leaching of dissolved solids from effluents through the alluvial deposits[24]. The total dissolved solids (TDS), a general indicator of water quality ranges from 77 to 275 mg/l, with a mean value of 151 mg/l. TDS is calculated by multiplying EC with 0.64 and is generally used to find the amount of contaminants present in the water[25,26]. The total hardness ranges from 75 to 196 mg/l, with a mean value of 120 mg/l. According to Lehr *et al.*[27] the water is moderately hard to hard at all sites, except site S15 which shows very hard water. The higher hardness is attributed to the presence of rich deposits of limestone and evaporates in the valley[28,29].

Among the cations (T_Z^+), Ca^{2+} ions are dominant in the cationic budget (Figure 3 *a*). The Ca^{2+} ion essential for bones and teeth varies from 23 to 45 mg/l with a mean value of 33 mg/l, whereas Mg^{2+} essential for membrane structure, varies from 4.4 to 23.9 mg/l with a mean value of 11.6 mg/l. The Na^+ concentration, essential for controlling fluid level and nerve conduction ranges from 6.3 to 15 mg/l, with a mean value of 9.5 mg/l. The K^+ concentration, necessary for muscle contraction ranges from 0.14 to 1.10 mg/l, with an average of 0.44 mg/l. Among the anions (TZ^-), the concentration of HCO_3^- (although having no adverse effects but should be within the permissible limits[30,31]), varies from 115 to 225 mg/l with a mean value of 163 mg/l, with zero phenolphthalein alkalinity. HCO_3^- is the dominant ion in the anionic budget, thus representing the total alkalinity of water (Figure 3 *b*). The alkalinity may be mainly due to soluble bicarbonates of Ca^{2+} and Mg^{2+}. Cl^-, essential for metabolism, varies from 1.8 to 10.7 mg/l, with an average value of 5.5 mg/l. On the other hand, SO_4^{2-}, essential for many biological processes such as for the formation of brain tissue and Mucin proteins in gut walls[32], varies from 1 to 25.3 mg/l with a mean value of 8.4 mg/l. The NO_3^- concentration, which is an index of anthropogenic activities, ranges from 3.5 to 14 mg/l with an average value of 10.8 mg/l. The SiO_2 concentration, essential in glass industry, varied from 1.8 to 19.2 mg/l, with an average of 19.4 mg/l, whereas the concentration of F^- ranges from 0.62 to 1.11 mg/l with an average value of 0.84 mg/l. Fluoride containing compounds are employed in artificial fluoridation of drinking water for the prevention of dental caries[33]. The order of cations was observed to be $Ca^{2+} > Mg^{2+} > Na^+ > K^+$, whereas the order of anions was $HCO_3^- > Cl^- > NO_3^{2-} > SO_4^{2-}$ in the present study. In general, the concentration of ions was lower during the high flow period than in the low flow period due to dilution effect of high discharge during high flow period.

To understand the source of these dissolved ions in water, the ratio Na/(Na + Ca) versus TDS was plotted on Gibbs diagram (Figure 4)[2]. As seen in the figure, the data falls in the region of rock dominance area, suggesting

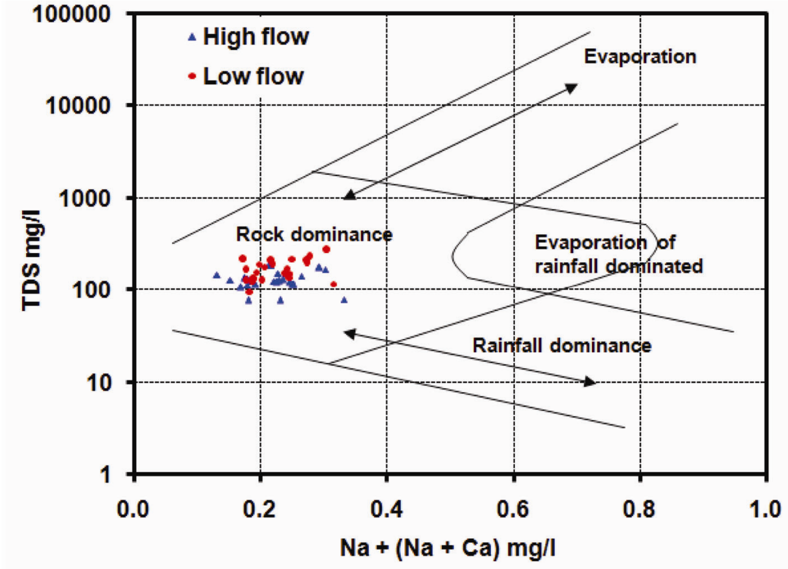

Figure 4. Gibbs diagram showing the mechanism controlling water quality of river water.

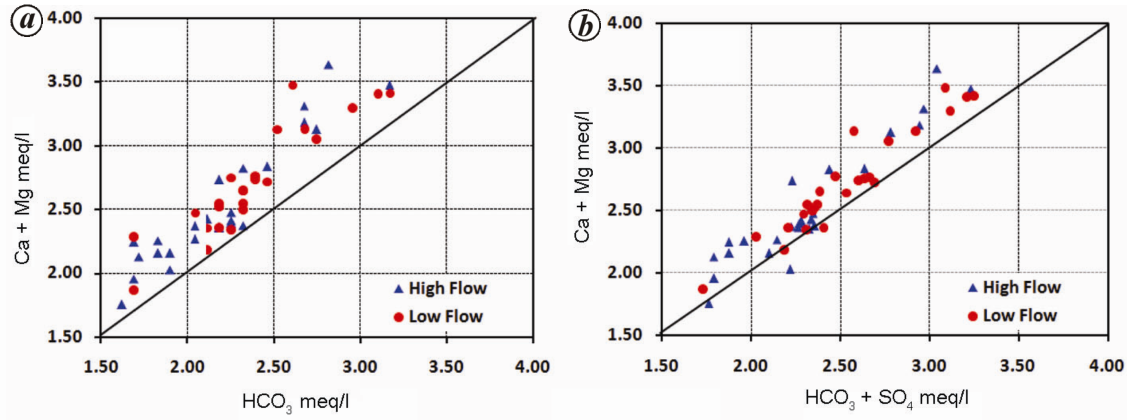

Figure 5. Scatter plots between Ca + Mg versus HCO_3 and Ca + Mg versus HCO_3 + SO_4.

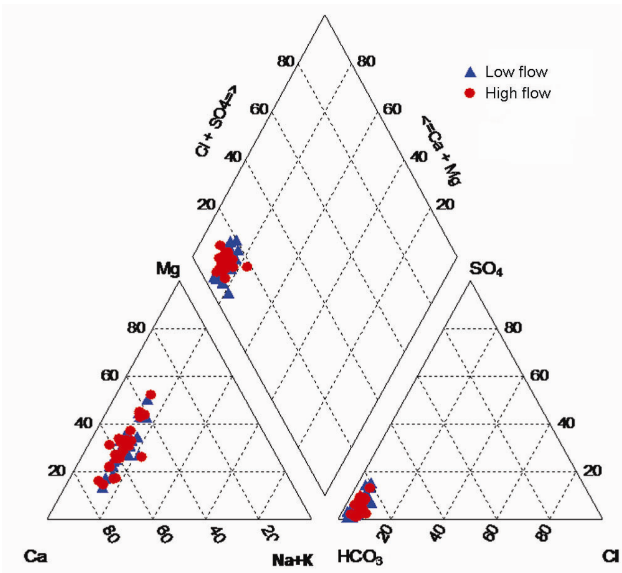

Figure 6. Piper diagram showing hydrochemical facies for high and low flow periods.

dissolution of various rock-forming minerals as the primary factor controlling the chemistry of waters of the River Jhelum and its tributaries. Furthermore, (Ca + Mg) versus HCO_3 (Figure 5 *a*) plot shows that the (Ca + Mg) content is slightly in excess of HCO_3, the excess magnitude being larger for most of the tributaries. Thus, the excess of (Ca + Mg) in these waters should be balanced by SO_4 and chloride (Figure 5 *b*). The plot also suggests that carbonate weathering is the major source of solutes in these waters for both periods. Since the dissolution of carbonate rocks proceeds more rapidly than silicates, it is the likely mechanism of solute acquisition. In addition, the trilinear piper diagram (Figure 6) shows that almost all the samples fall in the area of category 1, reflecting that alkaline earth (Ca^{2+}, Mg^{2+}) exceeds alkalis and weak acids HCO_3^- exceed other anions. More than >75% of the water samples fall within the normal-alkaline-earth water group. Three water types are identified: Ca–Mg–HCO_3, Mg–Ca–HCO_3 and Ca–HCO_3. The Ca–Mg–HCO_3 water type is the dominant facies at almost all the sites during

Figure 7. Field photographs during low flow period showing water supply schemes (***a***, ***b***) at site S13 (Kakapora) on main River Jhelum and (***c***) S14 (village Gundipora) on Romush nala. Irrigation lift stations at (***d***) S14 (village Gundipora) on Romush nala and (***e***, ***f***) site S13 (Kakapora) on main River Jhelum. Romush nala is a major tributary of River Jhelum. Schemes are established to supply water for domestic (including livestock) and irrigation purposes in the valley.

both periods. $Ca–Mg–HCO_3$ and $Mg–Ca–HCO_3$ are hybrid or mixed water types. About 72% of the samples show $Ca–Mg–HCO_3$ hybrid water types.

Water quality assessment

Domestic purposes

The quality of water is vital to mankind, because it has a direct connection with human welfare. The chemical characteristics play an important role to classify and assess the quality of water. The inherent quality of water makes it a suitable and important resource for sustainable development. In Kashmir valley, most of the areas are hilly and mountainous with inter-mountain valleys which are flat and mildly undulating. Under such conditions, small surface water streams/tributaries of River Jhelum are the most suitable source for domestic water supply. Moreover, along the River Jhelum and its tributaries a number of Government schemes are facilitating water supply to a large population in the valley (Figure 7 *a–c*). Therefore, to determine the potability of water of the Jhelum and its tributaries in terms of drinking, domestic and agricultural purposes, evaluation of quality based on comparison of chemical parameters, i.e. major ions with the international and national water quality standards such as WHO[6] and ISI[34] was carried out (Table 2). The range of concentration of chemical parameters of all the samples was well within the permissible limits prescribed by these organizations (Table 2). Therefore, the water of Jhelum and its tributaries can be regarded as potable and suitable for domestic and drinking purposes. Based on Carroll classification[35] (Table 3), the water of the study area falls in the fresh category with values well below the maximum permissible levels of 1500 mg/l (ref. 6). Water classification based on the hydrochemical properties and

TDS for water suitability suggests that all the samples (i.e. 100%) are below < 500 mg/l of TDS, which is desirable for drinking purposes without any risk[36,37].

Livestock purposes

Drinking water is widely available in the Kashmir valley. However, due to increase in quantitative or qualitative deterioration and deficiencies, several areas are under threat of facing water-scarcity scenarios. The quality variables for drinking water for livestock are almost the same as for humans, although the total permissible levels of total suspended solids and salinity may be higher[24]. To check salt imbalance, preventing poisoning by toxic constituents and from other diseases, the water consumed by livestock should be of high quality. Usually, TDS is the main parameter to evaluate the suitability of water for livestock. In the present case, water is good for livestock purposes as TDS in water ranges from 77 to 187 mg/l with a mean value of 130 mg/l during high flow period and from 95.42 to 275.20 mg/l with a mean value of 168.63 mg/l during low flow period. Based on the Australian and UNESCO standards, TDS value between 0 and 2900 mg/l is suitable for all animals[38].

Irrigation purposes

In the Kashmir valley, agriculture and its allied sectors including horticulture and sericulture are highly dependent upon the availability of water. A large numbers of canals (Zamaindari kuhl) are constructed by people to supply irrigation water to the fields. At many places along River Jhelum and its tributaries a number of Government canal schemes like lift schemes, diversion schemes and storage schemes have been established to provide irrigation facilities to the large track of cultivated and horticulture fields on upland (Karewas) regions and water-scarce areas (Figure 7 *d–f*). However, it is essential for water to meet the quality criteria of established standards; only then would it help achieve maximum crop productivity. The poor quality of water may bring undesirable elements to the soil in excessive quantities, thus affecting its fertility. To judge the suitability of water for irrigational purposes, parameters such as EC, %Na, SAR, MAR, RSC, USDA classification, KI and PI are used.

Electrical conductivity: According to Langanegger[39], the importance of EC is its measure of salinity. Water used for irrigation can vary greatly in quality depending upon type and quantity of dissolved salts. The high content of dissolved solids in water increases the salinity of soils that adversely affect the plants. Salts may harm plant growth physically by limiting the uptake of water through modification in the osmotic process[40]. The most influential water quality guideline on crop productivity is the water salinity hazard as measured by EC. The higher the EC, the less is the amount of water available to plants. Because plants can only transpire ‘pure’ water, usable plant water in the soil solution decreases dramatically as EC increases. Electrical conductivity of waters of the Jhelum and its tributaries shows wide variation, varying from 121 to 291 μs/cm with a mean value of 200.08 μs/cm during high flow period, whereas during low flow period EC ranges from 149.1 to 430 μs/cm with a mean value of 263.72 μs/cm. Water with EC less than 250 μs/cm is considered good and that with EC greater than 750 μs/cm unsuitable for irrigation. On the basis of EC, total concentration of soluble salts in irrigation water can be expressed as low (EC = <250 μS/cm), medium (EC = 250–750 μS/cm), high (EC = 250–2250 μS/cm) and very high (EC = 2250–5000 μS/cm) salinity zone for the purpose of irrigation water[41]. During high flow period three samples (12%) showed EC values more than 250 μs/cm whereas during low flow period 12 (48%) samples revealed higher values of EC. The higher concentration during low flow period is attributed to the lower discharge leading to least dilution effect on dissolved concentration of ions. In general, EC values were below 750 μs/cm, suggesting that the water is suitable for irrigational purposes.

Table 3. Water classes based on TDS

Category	TDS (mg/l)	Present study
Freshwater	<1000	100%
Brackish water	1000–10,000	–
Saline water	10,000–100,000	–
Brine	>100,000	–

Sodium per cent: Sodium is an important ion used for the classification of irrigation water because its reaction with the soil reduces its permeability[42,43]. The sodium in irrigation water is usually expressed as %Na (ref. 44) by the following equation[45]

$$\%\text{Na} = \frac{(\text{Na} + \text{K})}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})} \times 100.$$

Usually only minor problems occur when %Na values are less than 15%. When %Na > 15%, it will result in reduced permeability. The finer the soil texture and greater the organic matter content, greater will be the impact of sodium on water infiltration and aeration. Percentage of Na water of River Jhelum and its tributaries varies from 8.14 to 22.72 with a mean value of 13.84 during high flow period, whereas during low flow period, it ranges from 10.70 to 21.05 with a mean value of 14.03. As seen, the %Na values were well below the maximum sodium limit of 60% (ref. 30). Thus, the present study suggests that the water is good for irrigational purposes. A plot of analytical data on the Wilcox diagram[45] relating EC and percentage of sodium shows that the water is of very good quality and can be used for irrigation purposes (Figure 8).

Sodium adsorption ratio: SAR is an estimate of the degree to which sodium will be absorbed by the soil, which is used to evaluate the water quality for irrigation. The sodium or alkali hazard for irrigation is determined by the absolute and relative concentration of cations and is expressed in terms of SAR. If water used for irrigation is high in sodium and low in calcium, the cation-exchange complex may become saturated with sodium. This can destroy the soil texture owing to dispersion of the soil particles. In the present study, SAR has been calculated by the formula

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

The water has been classified in relation to irrigation based on the SAR values. Water with SAR ranging from 0 to 3 is considered good, while a value greater than 9 indicates that it is unsuitable for irrigation purpose. SAR of water of River Jhelum and its tributaries varied from 0.22 to 0.58 meq with a mean value of 0.35 meq during high flow period, and from 0.29 to 0.57 meq with a mean value of 0.37 meq during low flow period. These values are less than 10 and therefore fall in the 'excellent' category. Furthermore, plot of data on the US salinity diagram[46] also shows that most of the water samples fall in the category C1S1 and C2S1, indicating low to medium salinity and low sodium hazard. Thus, the water can be used for irrigation in most soils and crops with little danger of exchangeable sodium and salinity (Figure 9).

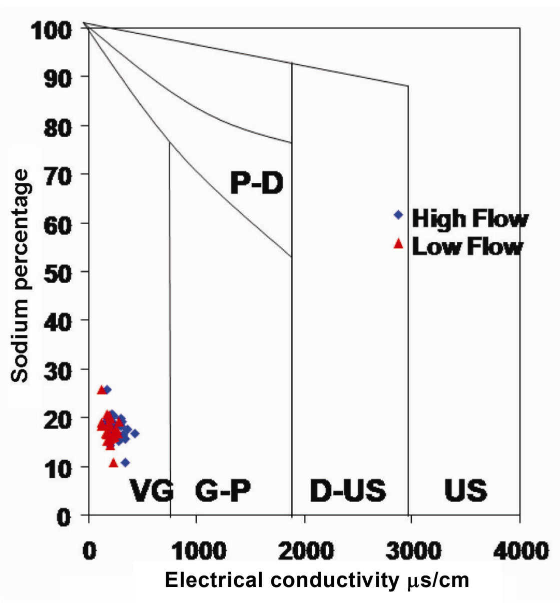

Figure 8. Wilcox diagram of water of high and low flow periods. VG, Very good; G, good; P, poor; D, dull, US, usable.

Residual sodium content: RSC is another important parameter to quantify the effects of carbonate and bicarbonates. A high value of RSC in the water leads to an increase in the adsorption of sodium by the soil[47]. According to United States Salinity Laboratory Staff (USSS)[46], irrigation waters having RSC values greater than 2.5 epm/l are considered harmful to the growth of plants; those with RSC values above 1.25 epm/l are not considered suitable for irrigation purposes, and waters with RSC values <1.25 meq/l are considered safe. RSC was calculated using the following relation[47]

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

The RSC of water of River Jhelum and its tributaries varies from 0.05 to 0.82 meq with a mean value of 0.34 meq during high flow period and 0.07 to 0.87 meq with a mean value of 0.34 meq during low flow period, indicating that the water is safe for irrigation purposes.

Magnesium absorption ratio: Magnesium hazard ratio was proposed by Szabolcs and Darab[48]. Paliwal[49] developed an index for calculating the magnesium hazard using the formula as

$$\text{MAR} = \frac{\text{Mg}}{(\text{Ca} + \text{Mg})} \times 100.$$

MAR value exceeding 50% indicates that the water is harmful and unsuitable for irrigation. The MR of water of River Jhelum and its tributaries varies from 16.68% to 60.10% with a mean value of 34.65% during high flow period; while it ranges from 15.45% to 57.64% with a mean value of 35.45% during the low flow period. In the present study, majority (80%) of samples fall under 50% MAR. The excessive magnesium in 20% of the samples may be due to the influence of dolomitic limestone in the catchment areas of these sites. In general, the results suggest that water is good for agricultural purposes.

United States Department of Agricultural classification: According to the USDA classification, EC < 250 µS/cm

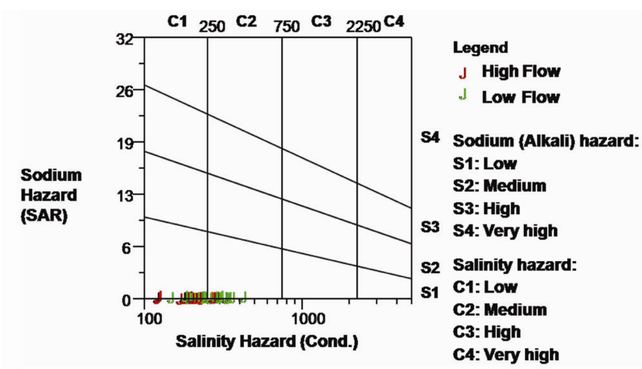

Figure 9. Salinity hazard diagram showing water classes for high and low flow periods.

is excellent (C1 class) 250–750 μS/cm is good quality (C2 class), 750–2250 μS/cm is of permissible quality (C3 class) and 2250–5000 μS/cm is unsuitable (C4 class) for irrigation purposes. The present observations suggest that suitability of water lies between C1 and C2 classes as TDS in waters ranges from 77 to 187 mg/l with a mean value of 130 mg/l during high flow period and from 95.42 to 275.20 mg/l with a mean value of 168.63 mg/l during low flow period, indicating that the water is good for irrigation purposes.

Kelly index: Kelly[50] and Paliwal[51] introduced an important parameter for evaluating quality of water for irrigation purposes using the formula

$$KI = \frac{Na}{(Ca + Mg)}.$$

KI of water of River Jhelum and its tributaries varies from 0.09 to 0.29 meq with a mean value of 0.16 meq during high flow period, whereas during low flow period it ranges from 0.12 to 0.26 meq with a mean value of 0.16 meq. All the values fall within the normal range (1), which suggests that groundwater is suitable for irrigational practice.

Permeability index: Doneen[52] suggested a criterion for evaluating the suitability of water for irrigation based on permeability index. According to this classification, classes I and II possess maximum PI > 75% and therefore, are good for irrigation, while the third category (class III) having 25% maximum PI is considered unsuitable for irrigation purposes[53]. PI is calculated using the equation

$$PI = \frac{(Na + HCO_3)}{(Ca + Mg + Na)} \times 100.$$

The PI of water of River Jhelum and its tributaries varies from 78.03% to 98.15% with a mean value of 88.74% during high flow period. During low flow period PI ranges from 77.26% to 97.19% with a mean value of 89.28%. Thus, the quality of water is good for irrigational purposes.

Conclusion

The chemical analysis of the waters of River Jhelum and its tributaries indicates that they are alkaline, moderately hard and fresh in terms of major cations and anions. The Ca^{2+} ion is the dominant cation and HCO_3^- is the dominant anion. The seasonal variations in discharge of the Jhelum riverine system play a dominant role in controlling the concentration of ions in water. In the present study, lower concentration of ions in water was observed during high flow period (summer season) due to higher melt from snow and glacier along with higher rainfall resulting in dilution effect on ionic concentration. Further, the water chemistry is dominantly controlled by the weathering of rocks particularly carbonate rocks. Broadly, three types of water have been identified, viz. Ca–HCO_3 type, Mg–Ca–HCO_3 and Ca–Mg–HCO_3. The river water is found to be suitable for drinking purposes on the basis of WHO and ISI standards. The water is also found to be excellent for irrigational purposes based on parameters such as EC, %Na, SAR, RSC, MAR, USDA classification, KI and PI. The present study will contribute towards the development of a database in terms of hydrogeochemical knowledge of the upper Jhelum basin in the Kashmir valley.

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