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Hydro-chemical characterization and quality assessment of a Western Himalayan river, Munawar Tawi, flowing through Rajouri district, Jammu and Kashmir, India

Mohd Zeeshan · P. A. Azeez

Abstract Studies on river water quality in the Indian Himalayas are limited to a few larger ones; the smaller ones, although vital for a large section of people, mostly remain untouched. Therefore, Munawar Tawi a tributary of Chenab flowing through Rajouri district of Jammu region, Western Himalayas was selected for the study. Fifty-four water samples from 27 sites from Rajouri town and its upstream and downstream locations were collected during January and June 2014. Fourteen water quality parameters that include major cations and anions were analyzed. Water quality indicators such as SAR, %Na, RSC, MAR, KI, and PI were also calculated to determine suitability of water for irrigation. Piper plots identified four water types, of which Ca^{2+}–Mg^{2+}–HCO^-_3 was the dominant type in both the seasons. While in January, water samples varied across all the four types, in June only two types were seen (i.e. Ca^{2+}–Mg^{2+}–HCO^-_3 and Ca^{2+}–Mg^{2+}–Na^+–HCO^-_3). Ludwig-Langelier plot also showed Ca^{2+}–Mg^{2+}–HCO^-_3 type as the dominant water type. Wilcoxon signed-rank test showed most of the parameters, except TDS,

significantly high in January than in June. Kruskal-Wallis test showed significant variation in concentration among most of the parameters from upstream to the town and towards downstream. The water, with respect to the set standards (WHO, ISI, UNESCO), in both January and June, is found suitable for drinking and irrigation.

Keywords Rajouri · Western Himalayas · Munawar Tawi · Water quality

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Introduction

Surface waters are highly susceptible to pollution especially due to discharge of wastewaters (Samarghandi et al. 2007). In most of the river basins, across the world, human activities have altered the fluxes of nutrients from the landscape to surface water leading to negative effects on water quality (Smith 2003). Growing industrialization, urbanization, and modern agricultural practices while increasing demand for fresh water deteriorate its quality (Carpenter et al. 1998; Chen et al. 2002; Yadav and Kumar 2011). Seasonal variation in precipitation, surface runoff, interflow, and ground water flow has a strong effect on river discharge and thus, on the concentrations of chemicals in the river water (Vega et al. 1998; Monavari and Guieysse 2007; Khadka and Khanal 2008; Twesigye et al. 2011). Irrigation with water of unacceptable quality leads to contamination of soil (Datta et al. 1997; Patel et al. 2004; Maréchal et al. 2006). Countries downstream to the Himalayas

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face constraints in access to water, and in addition, water pollution is one critical environmental problem in many parts of the area (Haloi and Sarma 2012). India with 4 % fresh water resources supports 16 % of the world population (Singh 2003) and with increasing population and consequent demand for water, conservation of river basins and other water sources is very crucial in the coming years. In the Himalayas, for the distinctive terrain, numerous streams (lower order ones such as primary, secondary, and tertiary) flowing through are the lifeline for majority of the inhabitants, several exquisite habitats, and species. Studies in Jammu & Kashmir (J&K) have focused on large rivers such as Jhelum, its tributaries (Khan et al. 2012; Rashid and Romshoo 2013; Mir and Jeelani 2015), lakes (Jeelani and Shah 2006; Sheikh et al. 2014), ground water (Jehangir et al. 2011), and large springs (Pandit et al. 2010). The lower order rivers, springs, and streams that are the main sources of water for all human needs are least studied. In this context, the present study selected Munawar Tawi, a third order river, that serves as the main source of water for domestic and agriculture purposes in Rajouri district. Munawar Tawi, largely free of anthropogenic pollution for there are no industries and urban centers in its upper reaches, on reaching the Rajouri town receives considerable amount of sewage and domestic wastes. Since there has been no study on Munawar Tawi, we felt it desirable to look at its quality, especially in view of its importance for the local people and the environment. We examined major water quality parameters in the river at Rajouri town and its upstream and downstream locations. Assessing the water quality of Munawar Tawi can serve as a baseline for future change analysis in view of growing industrialization and urbanization in the area and climate change.

Study area

Rajouri district lies at 33° 22′ to 33° 14′ N and 74° 7′ to 74° 39′ E (left to right) and 33° 34′ to 33° 6′ N and 74° 20′ to 74° 21′ E (top to bottom). The district, covering an area of 2769 km^2, is characterized with the Pir Panjal region, mountainous terrain and valleys, and topography ranging in altitude from 460 to 3900 mASL. The area is endowed with several springs, brooks, and rivulets that join to form the Munawar Tawi. People in Rajouri town and around depend on Munawar Tawi for their domestic, livestock, and irrigation needs.

Rajouri town and its outskirts, with 5663 houses and 35,995 people (Census of India 2011), is the most populated area in the district. The town is located almost 150 km west of Jammu city in the Western Himalayas. Munawar Tawi, originating from the Pir Panjal range of Thanamandi and Darhal, flows towards south entering Rajouri town (Fig. 1a). Then it takes a turn towards east to enter Chingus and then turns towards south through Nowshera and Sehot entering Punjab of Pakistan via a place called "Kot Maira." After 162 km from Rajouri town, Munawar Tawi joins Chenab as a right tributary at the place called "Marala" in Pakistan.

The climate of Rajouri district ranges from semitropical in the southern part to temperate in the northern part. Rajouri town falls in the temperate region. The district receives rainfall from the southwestern monsoon during June to August. During November to March, the northern part, particularly the catchment of Munawar Tawi, receives heavy snowfall. The district population, 483,284 in 2001, has increased to 619,266 in 2011 (Census of India 2011), a decadal growth of 28 %. Of the total land under cultivation in the district, 47.6 % is under maize, 46.3 % under wheat, and 5.4 % under rice (Digest of Statistics 2012). Maize is sown during April–May, while wheat is sown during October–November and reaped in April–May. Paddy is grown, mainly in fields close to the streams and river, with the onset of southwestern monsoon (May–June). Paddy and maize are reaped in September and October. The economy of the district is primarily based on agriculture. The agriculture fields spread along the banks of the river and other smaller streams, and surface water is the only source for irrigation.

Materials and methods

Water samples from 27 sites around the three locations (Rajouri town, its upstream and downstream, Fig. 1b) were collected along Munawar Tawi, in January and June 2014, for physicochemical analysis. Around each of the three locations, nine sites were identified and from each of the sites water samples were collected in triplicate (one each from each bank and center of the flow) and analyzed. Sampling was done twice from each site, in January representing winter and June representing summer flow. Although Munawar Tawi lacks specific discharge data, it would be highest in June and lowest during November to February similar to other rivers
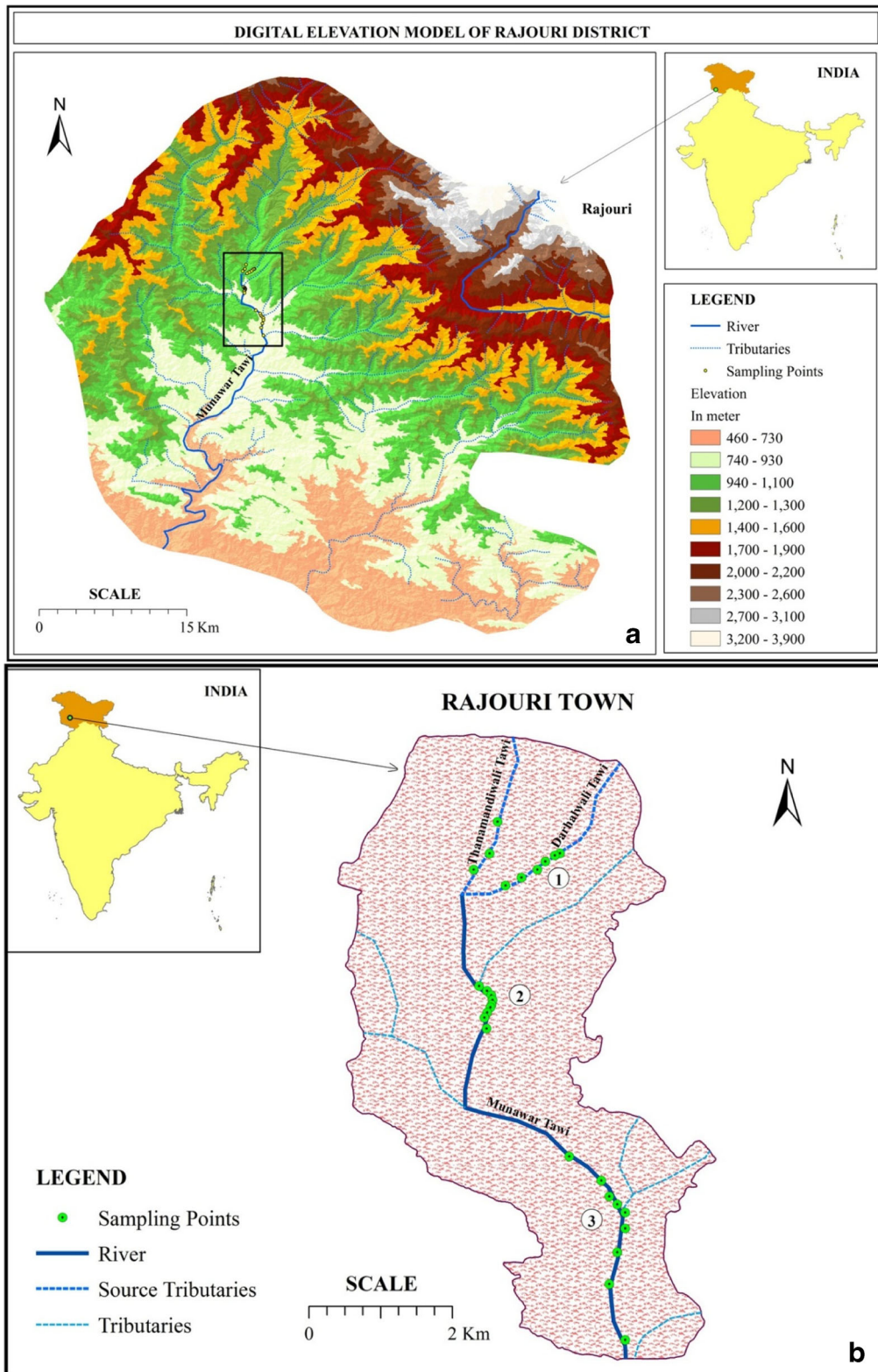
Fig. 1 **a** Elevation profile of the Munawar Tawi basin; **b** Rajouri town with its periphery, from location *1* (upstream) to *2* (highly populated area) and *3* (downstream)

originating from the Himalayas (Gulhati 1968; Sehgal 1999; Mir and Jeelani 2015). Samples were collected between 11:00 and 14:00 in 2-l polyethylene bottles, pre-cleaned with concentrated HNO_3, rinsed with distilled water, and then once with the river water before collecting the water sample. Samples were taken holding the bottle mouth open against the flow at 10 to 15 cm below the surface. The samples were stored at 0 °C for 2 days and then transported to the Environmental Impact Assessment (EIA) laboratory. In the laboratory, the samples were stored at 4 °C until analysis. All samples were analyzed within 10 days of reaching the laboratory. Samples, after filtering through <0.45-μm filter paper to separate suspended solids, were analyzed following the methods as per Federation and APHA (2005) and Tandon (2005). The physicochemical parameters analyzed include hydrogen ion concentration (pH), electrical conductivity (EC), turbidity, total dissolved solids (TDS), total hardness (TH as calcium carbonate), total alkalinity (TA as calcium carbonate), cations (Ca^{2+}, Mg^{2+}, Na^+, K^+), and anions (HCO_3^-, Cl^-, NO_3^-, SO_4^-). Of these, pH, EC, and TDS were measured directly on site using digital pH, EC, and TDS meters. TH was determined by EDTA (0.01 M) titration using ammonium buffer solution and Eriochrome black-T as indicator. Na^+ and K^+ ions were determined by a flame photometry (Systronics Flame Photometer-128). TA was determined by sulfuric acid titration using phenolphthalein and methyl orange as indicators. Ca^{2+} and Mg^{2+} were determined by EDTA (0.01 M) titration with sodium hydroxide (8 %) and murexide as indicator. HCO_3^- was estimated from the $CaCO_3$ levels (Rankin 2009). Cl was determined by titrating against $AgNO_3$ (0.02 N) using potassium chromate (5 %) as indicator. Turbidity was determined using standard turbidity suspension using a nephelometer (model-335). NO_3^- and SO_4^{2-} were determined by a spectrophotometer (Perkin Elmer Lambda-35 UV/VIS). Instrumental measurement was routinely checked by analyzing blanks, duplicates, and standards and by ensuring ion balances for quality control. The water quality was also compared with Bureau of Indian standards (ISI) and international standards by World Health Organization (WHO) for domestic use. Fitness of water for irrigation usage was checked based on EC as per US Department of Agriculture classification (USDA), sodium in % (%NA), sodium absorption ratio (SAR), residual sodium carbonate (RSC), magnesium absorption ratio (MAR), Kelly Index (KI), and permeability index (PI).

The AquaChem 2014.2 trial version was used to illustrate the hydro-geochemical characters as ternary plots for cations and anions [ternary plot, Piper plot, Ludwig-Langelier plot, and Schoeller plot].

Statistical analysis

To see the difference in each parameter of the samples collected during January and June, Wilcoxon signed-rank test was used. Water samples were classified into three groups based on its location, viz, samples collected from the town and its upstream and downstream locations. We used Kruskal-Wallis test to analyze the difference in the samples from upstream, town, and downstream in both January and June separately. All the analyses were conducted using the R (3.1.2). A correlation matrix (Krumbein and Graybill 1965) among different water quality parameters was also prepared.

Results and discussion

River water quality

A summary of the physicochemical characteristics of the water in Munawar Tawi collected from three locations during January 2014 and June 2014 is presented in Tables 1 and 2. In January, pH of water was alkaline and it was slightly higher in the downstream location. It was 8.2–8.4 in the upstream location, 8.3–8.4 in the town, and 8.2–8.6 in the downstream location. In June, pH was 6.3–6.4 in the upstream, 6.7–7 in the town, and 6.8–7 in the downstream. The pH, slightly acidic in June, gradually grew higher towards downstream. Increase in pH towards downstream would be due to sewage and domestic wastes flowing into the river. It would be also for the dissolution of limestone and dolomite-rich lithology in the flow path and drainage basin liberating Ca^{2+}, Mg^{2+}, and aluminosilicates into solution (Tijani 1994; Yongjun et al. 2006). TDS in the water was 40–60 mg/l in January while it was 75–112 mg/l in June, an increase similar to that reported from River Jhelum's tributaries (Mir and Jeelani 2015). Higher water flow in June probably hastens weathering of the substratum and erosion, which might be leading to the TDS increase. In June, the water flow is high from monsoonal rainfall and ice melt in the basin. Similar rise in TDS was also reported from Lidder River (Rashid and Romshoo 2013). EC was 220–280 μs/l in January and 149–

218 μs/l in June. EC, reflecting the amount of inorganic chemicals in the water (Bhardwaj and Singh 2011; Kumar et al. 2014), is higher in January possibly due to proportionately higher sewage entry. Higher EC could be also attributed to release of dissolved solids from upland areas through rainwater and from effluents (Ravindra and Garg 2007). TA (as $CaCO_3$) was 103.1–130.7 mg/l in January and 85–136.67 mg/l in June, closer in range during the former month than during the later month. Alkalinity in aquatic environment cushions against rapid change in pH, harmful to aquatic life. Na^+, essential for regulating fluid level and neural conduction in animals, varied between 10.4–15.5 mg/l in January and 8.1–14.2 mg/l in June. Concentration of Na^+ was in the order city > downstream > upstream in both the seasons. K^+, essential for muscle contraction in animals, was 2.1–3.5 mg/l in January, the values increasing in downstream direction. K was absent in June. Ca^{2+}, another vital element for life, was 45.4–64.8 mg/l in January. Its concentration varied in the order upstream > city > downstream. In June, Ca^{2+} was 43.1–62.2 mg/l, varying in the order upstream > downstream > city. Another biologically essential element, Mg^{2+} was 1.32–23.66 mg/l in January and 6.1–13.3 mg/l in June, falling in concentration towards downstream. TH ranges from 127.1–167.6 in January and 113.1–166.6 mg/l in June, increasing towards downstream. The hardness could be attributed to the presence of rich deposits of limestone and evaporation in the catchment (Raza et al. 1978; Hussain 2000). The water in the river in terms of hardness falls under the moderate class (Table 3, Sawyer and McCartly 1967). HCO_3^- is the dominant anion, in the range of 125.7–159.4 mg/l in January and 103.6–166.6 mg/l in June. Chloride in the water was in the range of 11.4–21.8 mg/l in June and 25.7–35.1 mg/l in January, increasing towards downstream. Increase in chloride towards downstream could be attributed to the inflow of domestic waste. SO_4^{2-} ranges between 7.72–15.39 mg/l in January and 1.72–8.08 mg/l in June. Turbidity was in the range of 3.2–4.6 NTU in January and 3.1–4.4 NTU in June. The turbidity of water is high, although close to permissible limit, possibly due to faster water flow, as the area is steep slope. Rajouri is a mountainous region, and many locations are prone to landslide and soil erosion, which also cause the water to be turbid. Nitrate, a key nutrient released through sewage, was 5.4–10.8 mg/l in January and 1.1–1.9 mg/l in June. Nitrate showed increase towards downstream in both the seasons. Geological formations of Rajouri

district vary from older metamorphic and crystalline in upper north to Murree group and Siwalik towards south (Fig. 1 under supplementary material); in Rajouri city and its surroundings, it is predominantly Murrees. In overall, the present study (Tables 1 and 2) shows that, except pH in June, all other water quality parameters were within the permissible limit as per both WHO and Indian standards (Bartram and Ballance 1996; Bureau of Indian Standards 2004; WHO 1996, 2011).

Considering all cations, their concentrations in January were in the order $Ca^{2+} > Mg^{2+} > Na^+ > K^+$; in the city and the downstream locations, the order was $Ca^{2+} > Na^+ > Mg^{2+} > K^+$. In June the order is $Ca^{2+} > Na^+ > Mg^{2+}$ in the upstream and the city, whereas it was $Ca^{2+} > Mg^{2+} > Na^+$ in the downstream. The order of anions was $HCO_3^- > CL^- > SO_4^{2-} > NO_3^{2-}$ in both January and June; Ca^{2+} was dominant among cations (Fig. 2a) and HCO_3^- was dominant among anions (Fig. 2b). To find the dominant hydro-chemical type of water in Munawar Tawi, the data was plotted on Piper diagram (Fig. 3, Piper 1944). According to the ionic concentrations, four types of water could be identified in the samples. In January, the dominant ions were $Ca^{2+}-Mg^{2+}-HCO_3^-$, $Ca^{2+}-HCO_3^-$, $Mg^{2+}-Ca^{2+}-HCO_3^-$, and $Ca^{2+}-Mg^{2+}-Na^+-HCO_3^-$. In June, only two types ($Ca^{2+}-Mg^{2+}-HCO_3^-$ and $Ca^{2+}-Mg^{2+}-Na^+-HCO_3^-$) are found. $Ca^{2+}-Mg^{2+}-HCO_3^-$ is the dominant water type in both the seasons. Recent studies in River Jhelum and Wular Lake (Sheikh et al. 2014; Mir and Jeelani 2015) report three types with Ca^{2+} and HCO_3^- as the dominant ions. The samples falling in the left corner of the Piper diagram show that the water is dominated by Ca^{2+}, Mg^{2+}, HCO_3^- (Sheikh et al. 2014). The Piper plot reveals the dominance of alkaline earth metals (such as Ca^{2+} and Mg^{2+}) over the alkaline elements (Na^+ and K^+). It also shows weak acid (HCO_3^- and CO_3^{2-}) exceeding strong acids (Cl^- and SO_4^{2-}, Mir and Jeelani 2015). Ludwig-Langelier plot of dominant cations and anions ($Ca^{2+} + Mg^{2+}$ vs. HCO_3^- and CO_3^{2-}) at 50 % ion balance (cations and anions each 50 %) suggests the water to be meteoric water (i.e. $Ca^{2+}-Mg^{2+}-HCO_3^-$) and indicates carbon lithology as a dominant source of major ions (Fig. 4a). A Ludwig-Langelier plot of other cations and anions (Na^+ and K^+ vs. Cl^- and SO_4^{2-}) shows slight increase towards Cl^- and SO_4^{2-} possibly indicating role of other sources in addition (Fig. 4b, Sheikh et al. 2014). Schoeller plots (developed by Schoeller 1967) display the concentrations of major ions in Munawar Tawi, the higher concentration (in meq/l) of

Table 1 Physicochemical quality of water in Munawar Tawi from upstream, city (Rajouri town), and downstream locations in January 2014 in contrast with desirable limit (DL) and permissible limit (PL) as per the WHO 1996; Bartram and Ballance 1996; WHO 2011 and ISI 2004 drinking water quality standards

Month—January	Location—upstream			Location—city			Location—downstream			WHO level		ISI level	
Parameter	Range	AVG	STD	Range	AVG	STD	Range	AVG	STD	DL	PL	DL	PL
pH	8.2–8.4	8.3	0.1	8.3–8.4	8.4	0	8.2–8.6	8.4	0.2	7–8.5	6.5–9.2	6.5–8.5	8.5
TDS (mg/l)	40–45	41.7	2.5	50–55	51.7	2.5	50–60	53.3	5	500	1500	500	2000
EC (µS/cm)	220–250	234.4	13.3	250–260	256.7	5	250–280	262.2	12	–	1600	800	4800
TA CaCO$_3$ (mg/l)	117.7–122.4	120.5	1.8	103.1–106.4	105	1.3	122.1–130.7	126.7	3.5	–	–	200	600
HCO$_3^-$ (mg/l)	143.5–149.2	146.9	2.2	125.7–129.7	128	1.6	148.9–159.4	154.5	4.3	–	–	–	–
Na^{2+} (mg/l)	10.4–12	11.2	0.6	14.6–15.5	15.1	0.4	12–13.5	12.7	0.6	–	200	–	–
K$^+$ (mg/l)	2.1–2.9	2.5	0.3	3–3.5	3.3	0.2	3.3–3.5	3.4	0.1	–	12	–	–
Ca^{2+} (mg/l)	45.4–47.9	46.8	1	53–57.7	55.3	1.8	60.8–64.8	63	1.5	75	200	75	200
T.H (mg/l)	127.1–141.4	135.3	6.1	146.3–152.3	149.6	2.5	163.1–167.6	165	1.9	–	–	200	600
Mg^{2+} (mg/l)	14.2–23.7	18.4	4	7.1–13.9	11.5	3.2	1.3–13.8	6.4	5.5	>30	150	30	100
Cl$^-$ (mg/l)	25.7–27.3	26.6	0.7	31.1–31.9	31.5	0.4	34–35.1	34.7	0.5	200	250	250	1100
TU (NTU)	4.2–4.6	4.4	0.1	3.3–3.9	3.6	0.2	3.2–3.6	3.4	0.2	–	–	1	5
NO$_3^-$ (mg/l)	4–4.5	4.3	0.3	4.2–5.3	4.7	0.5	3.2–9.4	6.1	2.7	–	50	45	100
SO$_4^{2-}$	7.7–9.4	8.6	0.6	12.1–15.4	13.7	1.2	12.1–14.4	13.5	0.7	200	400	150	400

Table 2 Physicochemical quality of water in Munawar Tawi from upstream, city (Rajouri town), and downstream locations in June 2014 in contrast with desirable limit (DL) and permissible limit (PL) as per the WHO 1996; Bartram and Ballance 1996; WHO 2011 and ISI 2004 drinking water quality standards

Month—June	Location—upstream			Location—city			Location—downstream			WHO level (2011)		ISI level (2004)	
Parameter	Range	AVG	STD	Range	AVG	STD	Range	AVG	STD	DL	PL	DL	PL
pH	6.3–6.4	6.3	0.1	6.7–7	6.8	0.1	6.8–7	6.9	0.1	7–8.5	6.5–9,2	6.5–8.5	8.5
TDS (mg/l)	75–85	80.2	4.1	85–112	102.1	11.7	99–106	102.6	2.5	500	1500	500	2000
EC (µS/cm)	149–161	154.7	4.8	203–212	206.8	3.4	207–218	212.7	4.4	–	1600	800	4800
TA CaCO$_3$ (mg/l)	85–97.3	91.7	4.6	100–111.7	105.6	3.9	123.3–136.7	129.4	4.6	–	–	200	600
HCO$^-_3$ (mg/l)	103.6–118.7	111.8	5.6	121.9–136.1	128.7	4.8	150.4–166.6	157.8	5.7	–	–	–	–
Na^{2+} (mg/l)	8.1–9.4	8.8	0.5	13.3–14.2	13.7	0.4	10.1–12.3	11.4	1	–	200	–	–
K$^+$ (mg/l)	0–0	0	0	0–0	0	0	0–0	0	0	–	12	–	–
Ca^{2+} (mg/l)	42.1–46.3	45	1.4	48.2–51	49.6	1	51.3–62.2	56.6	4.3	75	200	75	200
T.H (mg/l)	113.3–129.3	122.4	5.8	130–136.7	133	2.2	140–166.7	153.1	10.5	–	–	200	600
Mg^{2+} (mg/l)	6.1–10.6	7.8	1.6	7.3–11.6	9.1	1.3	10.7–13.3	11.9	0.8	>30	150	30	100
Cl$^-$ (mg/l)	11.4–16.5	14.8	2.4	18.7–21.8	20.6	1.4	18.7–21.7	20.6	1.3	200	250	250	1100
TU (NTU)	4.1–4.3	4.2	0.1	3.1–4.4	3.7	0.5	3.5–4.2	3.8	0.3	–	–	1	5
NO$^-_3$ (mg/l)	1.1–1.7	1.4	0.3	1.3–1.5	1.4	0.1	1.4–1.9	1.7	0.2	–	50	45	100
SO$^{2-}_4$	1.7–6.9	5.3	1.6	5.6–8.1	6.9	0.7	4–6.5	5.3	0.7	200	400	150	400

Table 3 Classification of water for its suitability to drinking based on TDS into fresh, brackish, saline, and brine water as per Carroll (1962) and excellent, good, fair, poor, and unacceptable as per WHO (1996); Bartram and Ballance (1996) and total hardness (TH) as CaCO$_3$ as per Sawyer and McCartly (1967)

Parameters	Range	Class	January samples in %	June samples in %
TDS (mg/l)	<1000	Fresh water	100	100
	1000–10,000	Brackish water		
	10,000–1,00,000	Saline water		
	>1,00,000	Brine		
TDS (mg/l)	<300	Excellent	100	100
	300–600	Good		
	600–900	Fair		
	900–1200	Poor		
	>1200	Unacceptable		
TH	<75	Soft		
	75–150	Moderately	48.1	77.8
	150–300	Hard	51.9	22.2
	>300	Very hard		

Ca^{2+} followed by Mg^{2+} among cations and HCO$_3^-$ among anions (Fig. 5).

Wilcoxon signed-rank test shows that of all the parameters in Table 4, TDS increases, while EC, Na$^+$, K$^+$, Ca^{2+}, TH, Cl$^-$, NO$_3^-$, and SO$_4^{2-}$ significantly decrease from January to June. In the case of TA, pH, HCO$_3^-$, and Mg^{2+}, the seasonal changes are insignificant. With respect to locations towards downstream in January, Kruskal-Wallis test shows pH and NO$_3^-$ as insignificant. TDS, EC, K$^+$, Ca^{2+}, TH, and Cl$^-$ increased significantly whereas Mg^{2+} and TU decreased significantly. TA and HCO$_3^-$ are significantly less in the town and higher in the downstream. In June, Kruskal-Wallis test shows Na$^+$ and SO$_4^{2-}$ decreasing significantly towards upstream. All parameters, except the TU, increase significantly

towards downstream (Table 4). In the case of TU, the highest was in the upstream possibly for the low flow in the river.

Correlation matrix of 13 variables for January and June is given in Table 5. TDS, EC, Na$^+$, K$^+$, Ca^{2+}, TH, and Cl$^-$, show significant positive correlations with each other during both the seasons. On the other hand, TU and Mg$^+$ showed significant positive correlation with each other and negative correlation with the rest of the parameters except HCO$_3^-$ in January. There were also notable differences between seasons in the correlations among some of the parameters. In June, TU shows significantly negative correlation with all the parameters except HCO$_3^-$, Cl$^-$, and SO$_4^{2-}$. In January, SO$_4^{2-}$ shows significantly positive correlation with other parameters
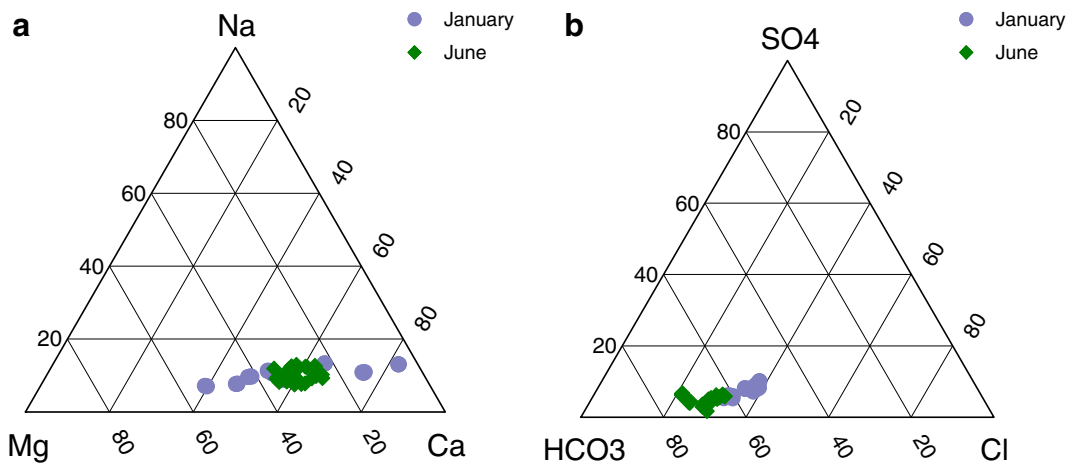
Fig. 2 Ternary plot showing **a** cations and **b** anions composition in Munawar tawi water in January and June
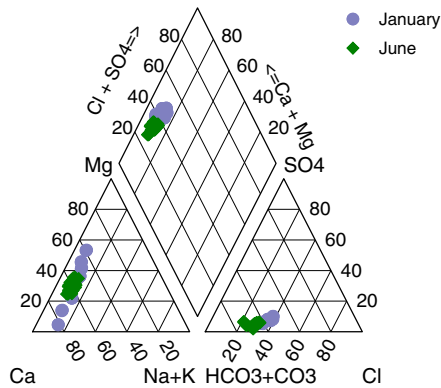
Fig. 3 Piper diagram showing hydro-chemistry of Munawar tawi in January and June

Fig. 5 Schoeller plot

except pH and NO_3^-, while in June it did not show any correlation with any parameter except Na^+. pH showed significantly positive correlation with TDS in January and with all other parameters except TU, NO_3^- and SO_4^{2-} in June. HCO_3^- shows significantly negative correlation with Na^+ and positive correlation with NO_3^- in January. HCO_3^- in June shows significantly positive correlation with all the parameters except TU and SO_4^{2-}. Overall, these correlations show influence of sewage, domestic, agriculture activities, and seasonal variations due to water flow. Moreover, this would also reflect variation in the source of each of the ionic content in water.

Water quality for domestic, livestock, and irrigational purposes

To check the usability of the water in the Munawar Tawi, important water quality parameters were
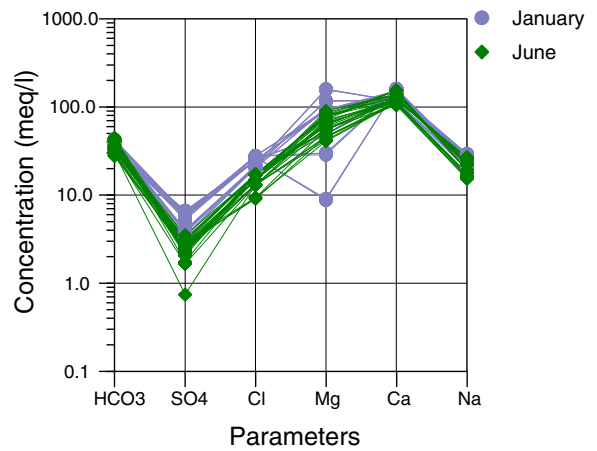
compared with WHO and ISI standards (Tables 1 and 2). Except the pH in June, which is slightly acidic, other parameters were within the permissible limits. Based on the classification (in Table 3) by Carroll (1962), Munawar Tawi falls in fresh water category. The water, which is having TDS <500 mg/l, is also fit for drinking (Freeze and Cherry 1979). Permissible quality of drinking water for livestock is similar to that for humans except that TDS and salinity could be a bit higher (Ravindra and Garg 2007). Australian and UNESCO standards approve TDS below 2900 mg/l for livestock (Hamill and Bell 1986). In our study, the levels of TDS are below 300 mg/l in both the seasons (Table 3). In Rajouri, rain-fed agriculture is widespread, unlike in the plains where groundwater is also available for irrigation. People in the district are dependent on agriculture and allied sectors for
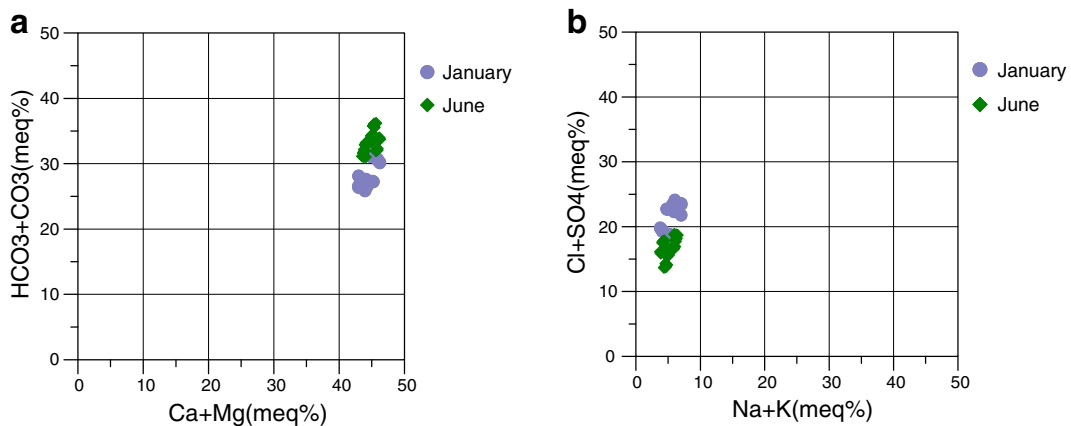
Fig. 4 Ludwig-Langelier plot **a** dominant cations and anions; Ludwig-Langelier plot **b** other available cations and anions

Table 4 Results of the Wilcoxon signed-rank test to examine significant difference in the parameters of the water samples collected in January and June and Kruskal-Wallis (KS) test to examine the changes based on locations (upstream, city, and downstream)

Parameters	V	$P<$	KS—January samples			KS—June samples		
			chi-square	df	$P<$	chi-square	df	$P<$
pH	378	0.001	3.1	2	0.1	17.61	2	0.001
TDS	0	0.001	19.4	2	0.001	16.77	2	0.001
EC	378	0.001	15.14	2	0.001	20.82	2	0.001
$CaCO_3$	258	0.1	22.61	2	0.001	23.16	2	0.001
Na^{2+}	372	0.001	10.68	2	0.001	23.19	2	0.001
K^+	378	0.001	18.51	2	0.001	0	0	0
Ca^{2+}	357	0.001	23.14	2	0.001	23.18	2	0.001
TH	378	0.001	23.16	2	0.001	23.15	2	0.001
Mg^{2+}	252	0.1	18.99	2	0.001	17.66	2	0.001
Cl^-	378	0.001	23.37	2	0.001	17.48	2	0.001
TU	110	0.1	19.78	2	0.001	9.71	2	0.001
NO_3^-	378	0.001	2.69	2	0.2	8.93	2	0.05
HCO_3^-	258	0.1	22.61	2	0.001	23.16	2	0.001
SO_4^{2-}	378	0.001	17.36	2	0.001	12.11	2	0.05

V Wilcoxon signed-rank test, df degree of freedom, and P significance

livelihood. A large number of Kuhl (community managed traditional water harvesting and transport system) are constructed to supply irrigation water mainly for rice cultivation. As per USDA classification, the levels of EC, %Na, SAR, MAR, RSC, KI, and PI are considered to decide the suitability of the water for irrigation.

Electrical conductivity (EC)

EC, a measure of salinity (Langanegger 1989) and dissolved solids in water, when high in irrigation water, raises the salinity of soils affecting the plants by limiting the uptake of water through a reversal in the osmotic process (Todd 1980). Overall, EC of Munawar Tawi was below <300 μS/cm. As per the criteria by Wilcox (1955) in terms of EC, 55 % water samples of Munawar Tawi in January are found be "excellent" and 45 % of "good quality". On the other hand, in June, all samples fell in "excellent" category (Table 6). EC in the city and downstream is >250 μs/cm in January, which can relate to the low water flow than in June; consequently lower dilution of dissolved ions.

Sodium percentage (%Na)

Sodium percentage (%Na) is a common index used for assessing the suitability of irrigation water. It is defined by Wilcox (1955) as follows.

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

Higher %Na in irrigation water is known to reduce the permeability of soil and hence, is important for deciding the suitability of water for irrigation. The impact of high %Na is higher on the soil with coarser texture and higher organic matter. %Na in water of Munawar Tawi varies from 11.25 to 17.96 (mean = 14.73) in January. In June, it ranges from 9.78 to 16.38 (mean = 12.96). Basing on the criteria by Eaton (1950) and Wilcox (1955), %Na in the water in the river falls is "excellent" class (Table 6).

Sodium adsorption ratio (SAR)

Water having high Na^+ and low Ca^{2+} favors saturation of the binding sites in the soil with Na^+ by ion exchange and destroys soil structure (Todd 1980) resulting in fall in productivity (Subba Rao 2006). Soil permeability

Table 5 Correlation matrix of ionic content of Munawar Tawi during January and June

		pH	TDS	EC	HCO_3^-	Na^{2+}	K^+	Ca^{2+}	T.H	Mg^{2+}	Cl^-	TU	NO_3^-	SO_4^{2-}
January	pH	1												
	TDS	0.41	1											
	EC	0.34	0.61	1										
	HCO_3^-	0.2	−0.15	0.06	1									
	Na^{2+}	0.19	0.57	0.63	−0.7	1								
	K^+	0.27	0.78	0.83	−0.08	0.65	1							
	Ca^{2+}	0.29	0.7	0.74	0.27	0.38	0.74	1						
	T.H	0.23	0.73	0.58	0.25	0.28	0.66	0.95	1					
	Mg^{2+}	−0.32	−0.44	−0.82	−0.28	−0.42	−0.67	−0.82	−0.61	1				
	Cl^-	0.23	0.79	0.67	0.13	0.44	0.79	0.97	0.97	−0.7	1			
	TU	−0.4	−0.76	−0.75	−0.05	−0.58	−0.7	−0.94	−0.86	0.82	−0.91	1		
	NO_3^-	0.45	0.01	0.64	0.44	0.13	0.32	0.51	0.34	−0.71	0.31	−0.44	1	
	SO_4^{2-}	0.27	0.69	0.67	−0.23	0.7	0.85	0.79	0.74	−0.65	0.84	−0.8	0.36	1
June	pH	1												
	TDS	0.76	1											
	EC	0.94	0.86	1										
	HCO_3^-	0.78	0.72	0.82	1									
	Na^{2+}	0.84	0.71	0.83	0.47	1								
	K^+	0	0	0	0	0	1							
	Ca^{2+}	0.69	0.66	0.8	0.85	0.4	0	1						
	T.H	0.67	0.62	0.78	0.85	0.38	0	0.99	1					
	Mg^{2+}	0.73	0.6	0.7	0.78	0.43	0	0.75	0.77	1				
	Cl^-	0.77	0.71	0.86	0.63	0.76	0	0.7	0.7	0.6	1			
	TU	−0.42	−0.22	−0.4	−0.14	−0.33	0	−0.22	−0.21	−0.19	−0.07	1		
	NO_3^-	0.42	0.38	0.34	0.56	0.03	0	0.57	0.52	0.58	0.32	0.15	1	
	SO_4^{2-}	0.47	0.35	0.34	0.18	0.52	0	0.2	0.12	0.23	0.32	0.07	0.34	1

decreases due to increase in Na^+ in relation to Ca^{2+} and Mg^{2+} contents and inhibits water intake by crops. SAR was estimated using the formula (Hem 1991) given below.

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

The SAR levels, expressed in meq/l, range from 10.36–16.26 (mean = 13.11) in January, while in June the range was 9.44–15.56 (mean = 12.1). In the present study, with respect to SAR based on WHO (1989) classification, 33.3 % water samples in June fell in "excellent" category, while the rest of the samples in June and all samples in January fell under "good" category (Table 6). On comparing the data of both the months with US salinity laboratory diagram (USSL; Richards 1954), also known as Wilcox diagrams, to find the suitability

of river water for irrigation, it was found that 100 % of the water samples of June fall in C1 class indicating low salinity. Only 33.3 % fell in S1 class and 66.6 % in S2 class indicating low to medium sodium hazard (Table 6). In January, 55.6 % water samples fall in C1 class and 44.4 % in C2 class indicating low to medium salinity. In January, 100 % of the samples fall in S2 group indicating medium sodium hazard. In short, in terms of SAR, the water from Munawar Tawi is suitable for irrigation.

Residual sodium carbonate (RSC)

An excess amount of HCO_3^- and CO_3^{2-} over the sum of Ca^{2+} and Mg^{2+} also influences the suitability of groundwater for irrigation as these ions

Table 6 Classification of water based on its suitability for irrigation usage; EC and %Na after Wilcox (1955); SAR and RSC after Richards (1954); MAR by Paliwal (1972); and KI after Kelley (1951)

Parameter	Range	Class	January samples in %	June samples in %
EC	<250	Excellent (C1*)	55.6	100
	250–750	Good (C2*)	44.4	
	750–2000	Permissible (C3*)		
	2000–3000	Doubtful (C4*)		
	>3000	Unsuitable (C4*)		
%Na	<20	Excellent	100	100
	20–40	Good		
	40–60	Permissible		
	60–80	Doubtful		
	>80	Unsuitable		
MR	<50	Suitable	100	100
	>50	Unsuitable		
RSC	<1.25	Safe	100	100
	1.25–2.5	Marginally suitable		
	>2.5	Not suitable		
SAR	<10	Excellent (S1*)		33.3
	10–18	Good (S2*)	100	66.6
	18–26	Permissible (S3*)		
	>26	Doubtful (S4*)		
KI	<1	Suitable	100	100
	>1	Unsuitable		

*Classification of irrigation water based on US salinity diagram. S1: low, S2: medium, S3: high, S4: very high for sodium hazard, C1: low, C2: medium, C3: high, C4: very high for salinity hazard

cause damage to soil texture by dissolving organic matter in the soil (Kumar et al. 2007). This excess of HCO_3^- and CO_3^{2-} over Ca^{2+} and Mg^{2+} is called RSC. Adsorption ratio of sodium increases with an increase in RSC value in the soil (Eaton 1950). RSC is calculated using the following formula (Ragunath 1987).

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

RSC, expressed in meq/l, ranged from −1935.67 to −701.4 (mean = −1393) in January. The values were −1587.15 to −763.42 (mean = −1125.22) in June. Based on the classification by Richards (1954), all water sample are "safe" (Table 6) for irrigation.

Magnesium adsorption ratio (MAR)

In water, Ca^{2+} and Mg^{2+} always maintain a state of equilibrium (Hem 1985). Excess Mg^{2+} in water increases the alkalinity of soil that results in a decrease in crop productivity (Kumar et al. 2007). Magnesium hazard ratio, proposed by Szabolcs and Darab (1964), is calculated by the formula (Paliwal 1972) given below.

$$MAR = (Mg^{2+}) * 100 / (Ca^{2+} + Mg^{2+})$$

MAR, expressed in percentage in January ranged from 1.97–33.51 (mean = 17.98). In June, the values were in the range of 12–19.39 (mean = 15.86). Therefore, water of Munawar Tawi falls within the permissible limit of MAR (Table 6) which affirms its suitability for irrigation purposes.

Kelly index

Kelley (1951) introduced sodium measurement against Ca^{2+} and Mg^{2+} to calculate Kelly's ratio. Kumar et al. (2007) opines that SAR is a better measure for the purpose. Nevertheless, we

estimated KI to evaluate our sample using the formula given below.

$$KI = Na^+/(Ca^{2+} + Mg^{2+})$$

In the case of the water samples in the present study, KI expressed in meq/l ranged from 0.11–0.20 (mean = 0.15) in both January and June. Thus, as per KI, the water in the river falls in the suitable category (Table 6) for irrigation.

Permeability index (PI)

Generally, long-term irrigation altered soil permeability due to accumulation of Na^+, Ca^{2+}, Mg^{2+}, and HCO_3^- contents in the soil due to inadequate drainage over a period. To assess suitability of water for irrigation, Doneen (1964) evolved an index estimated using the formula given below.

$$PI = (Na^+ + \sqrt{HCO_3^-}*100/(Ca^{2+} + Mg^{2+} + Na + K)$$

The PI, expressed in meq/l, in the present study ranged from 10.98–17.23 (mean = 14.05) in January. PI for the June samples were 10.88–17.59 (mean = 14.2). The entire sample values fell in Class 1 of Doneen's chart (Domenico and Schwartz 1990) indicating suitability of the water for irrigation.

Conclusion

The study examined the water quality of Munawar Tawi flowing through Rajouri town. Water collected from three locations, viz the town, its upstream, and downstream, was alkaline (pH .3) in January. It turned slightly acidic (pH .7) in June. Wilcoxon signed-ranks test shows TDS significantly higher in June than in January, which can be due to higher flow during the latter month. pH, EC, Na^+, K^+, Ca^{2+}, TH, Cl^-, NO_3^-, and SO_4^{2-} which are significantly lower in June than in January can be due to dilution. The study also found that all the parameters, except TU and Mg^{2+}, were significantly higher in town and downstream locations, perhaps for sewage and domestic flow from the town. Piper plot and Schoeller plot show Ca^{2+} among the cations and HCO_3^- among anions as dominant ions. Ionic chemistry reveals the water meteoric. Hydro-chemical analysis of Munawar Tawi shows the concentration of major ions to be within permissible limit as per WHO, ISI, and UNESCO standards, indicating that water is suitable for humans and livestock uses. Based on EC, %Na, and SAR, the water falls in "excellent" to "good" categories and considering RSC, MAR, KI, and PI, water falls under "safe and suitable" category for irrigation. We suggest that the smaller rivers in the Himalayas need to be studied intensively and extensively and more frequently as that would contribute towards the database for use in the context of interpreting imminent climate changes.

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