



# Water quality evaluation of the upper stretch of the river Jhelum using multivariate statistical techniques

Riyaz Ahmad Mir<sup>1</sup> · Khalid Muzamil Gani<sup>2</sup>

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## Abstract

Water quality assessment is considered essential for the evaluation of river pollution and its variation, resulting due to either natural or point/non-point anthropogenic sources. This study describes the water quality of the upper stretch of the Jhelum River located in Kashmir Himalaya using multivariate statistical techniques. The descriptive statistics and correlation matrix were applied to explore the correlations between the determined water quality variables whereas; principal component/or factor analysis (PCA/FA) was employed to take out the important factors that control the seasonal water quality variations. The hierarchical cluster analysis (HCA) was employed for the extraction of monitoring stations that can be developed for continuous water quality assessment in this area. Based on the PCA/FA, 95.7% of the total variance in the summer season was described by six factors while 85.8% of the total variance, in the winter season, was described by only four factors. HCA based on two seasons and different levels of pollution grouped the sampling stations into 3 classes described as low-, medium-, and high-pollution regions. Overall, the results illustrated that river water quality has deteriorated progressively from upstream to downstream areas and the methodology adopted can be used for the subsequent water quality surveys to highlight any temporal evolution of river water quality.

**Keywords** Jhelum River · Statistics · Multivariate · Water quality · Influencing factors

## Introduction

The river water quality is affected by pollution from anthropogenic and natural routes. The urban, agricultural, and industrial activities are the main anthropogenic sources of pollution. However, the input from precipitation, erosion, and weathering of crustal materials are the natural sources (Karbassi et al. 2008; Nouri et al. 2008) of pollution. From prehistoric times, the riverine systems have played an essential role in the development of human civilizations by providing an essential and easily accessible fresh water supply for domestic, irrigation, and industrial purposes. However, the rivers across the globe have

been heavily influenced by discharging of untreated or partially treated wastewater. Considering these facts, it is thus very imperative to continuously assess the river water quality through an ample and effective approach such as the long-term water quality monitoring surveys and programs for sustainable water management strategies. It is notable that such programs may produce large datasets for which the interpretation of underlying meaningful information often becomes difficult (Shrestha and Kazama 2007). Therefore, the application of multivariate analysis and data reduction techniques has a significant role. The multivariate statistical techniques of cluster analysis (CA), principal component analysis (PCA), or factor analysis (FA) have been often applied for the data interpretation of multidimensional measurements of water quality datasets, assess water quality, understand temporal and spatial variations, and identify latent sources of pollution to the river (e.g., Mavukkandy et al. 2014; Wang et al. 2014; Kumarasamy et al. 2014; Pati et al. 2014; Thareja 2014; Khalil et al. 2014).

There are a number of studies which reported the degradation of water resources of the valley such as lakes and streams. For instance, Mushtaq and Pandey (2014) reported the deterioration of Wular Lake, Asia's largest freshwater lake due to

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✉ Riyaz Ahmad Mir  
riyazgsi@gmail.com

<sup>1</sup> Department of Earth Sciences, Indian Institute of Technology Roorkee, Roorkee -247667, India

<sup>2</sup> Institute for Water and Wastewater Technology, Durban University of Technology, Durban -4001, South Africa

the anthropogenic impact and changes in the land use/land cover (LULC) and hydrometeorological climate of the region. Mushtaq and Lala (2017) also reported that due to the changes in LULC and consequent hydrological changes like decreased runoff, increased erosion and sedimentation reduce the water holding capacity of lake day by day, thus leading to Wular Lakes deterioration. Showqi et al. (2014) studied the spatio-temporal changes pertaining to LULC and the driving forces behind these changes in Doodhganga watershed of the Jhelum Basin. The study reported that the increasing human population together with decreasing stream discharge account for LULC changes in the watershed. Rasool et al. (2018) reported that changing climatic trends proved to be the triggering factors supporting for the land use conversion, in the areas of Shopian district of Kashmir valley. Rashid et al. (2011) reported that in the Budgam area of Kashmir Himalaya about 13.19% of the area has undergone moderate to high degradation, whereas about 44.12% of the area has undergone slight degradation. Rashid et al. (2017a, b) reported that the Dal Lake has witnessed significant changes in LULC in and around its vicinity due to unplanned urbanization, high population growth, and nutrient load from intensive agriculture and tourism. Nanda et al. (2014) studied the LULC of the Vishav watershed. The growing population and incrementing influence of the unplanned developmental processes are the main forces behind the major shift of forest and agricultural lands into horticulture and other categories. Rashid and Romshoo (2013) studied the causes of deteriorating water quality in the Lidder stream which is one of the main tributaries of the Jhelum River in Kashmir Himalaya. They reported that the total phosphorus, orthophosphate phosphorus, nitrate nitrogen, and ammonical nitrogen showed higher concentration in the months of July and August, while the concentration of dissolved oxygen decreased in the same period, resulting in deterioration in its water quality. Moreover, tourism influx and extensive use of fertilizers and pesticides in the agriculture and horticulture lands during the growing season (June–August) are also considered responsible for the deteriorating water quality. Rashid et al. 2017a, b reported that the changes in the LULC, above ground biomass (AGB), and the associated above ground carbon (AGC) stocks have an adverse effect on the carbon sequestration potential of the area which is already facing the brunt of climate change.

Likewise, the water quality of Jhelum River in Kashmir valley has been drastically influenced by the ever-rising anthropogenic activities in its catchment (Mir et al. 2016, Mir and Jeelani 2015). For example, the extensive changes in land use (Romshoo and Rashid 2014), spontaneous urbanization (Sajjad and Iqbal 2012), forest cover degradation/or deforestation (Singh et al. 2012), high tourism pressures (Mushtaq and Pandey 2013), landform degradation (Zaz and Romshoo 2012), and uncontrolled use of fertilizers and pesticides (Mir et al. 2016) have seriously affected the biological and

physicochemical properties of water resources in the Valley. Similarly, a number of recent studies have focused to study the water quality of the Jhelum River and its different tributaries (e.g., Mir et al. 2016; Mir and Jeelani 2015; Rather et al. 2016). However, the datasets are mostly analyzed using conventional analytical techniques. In this study, multivariate statistical techniques (i.e., descriptive and multivariate statistics, PCA/FA, HCA, etc.) have been used to study and locate the sources of pollution of the river and the spatio-temporal variations of surface water quality, and to locate the proper stations for continuous water quality monitoring in the area. The study area selected includes the upper stretch from District Anantnag to District Srinagar of the Jhelum River of the Kashmir valley located in western Himalaya. In this study, a strategy is proposed (1) to find out the critical variables that control the spatio-temporal variations in water quality, (2) to understand the spatio-temporal variations in water quality, and (3) to identify underlying pollution factors that determine the corresponding significant water quality parameters of the river.

## Study area

The Jhelum River originates from the major springs in the Anantnag district of the Kashmir valley located in western Himalaya. The river Jhelum is a complex drainage system of a number of tributaries originating from the Pir-Panjal and Greater Himalayan ranges from both sides while flowing southeast to northwest into Wular Lake, a freshwater lake. After leaving the lake near Sopore, the river takes a westerly flow direction to depart through a gorge in the Pir-Panjal mountain range near Kichhama Baramullah to enter into the Pakistan territory. The Jhelum River almost traverses the whole Kashmir valley from its origin to the outlet. The river and its streams are perennial in nature receiving the meltwater produced from the snow and glacier cover of the Himalayan and Pir-Panjal mountain ranges. Due to the melting of high-altitude snow and glaciers supplemented occasionally with seasonal rainfall, the peak discharge is observed in May and June. Due to the snow accumulation/freezing from October to February, a low peak discharge is observed in this period (Mir et al. 2016).

The present work focuses on the upper stretch of the Jhelum River from Khanabal in Anantnag district to Zero bridge in Srinagar district (Fig. 1). In this study, the sampling stations were selected from upstream to downstream that is from Anantnag district located in upstream areas through Pulwama to Srinagar districts located in downstream areas. As per the locality name, the sampling stations were named and a specific sampling station Id was given to each station. The sampling stations were selected at Khanabal, Batango, Bijbehara, Nayana, and Sangam of district Anantnag and designated as J1, J2, J3, J4, and J5. However, two samples stations were selected at Awantipora and Galander labeled as J6

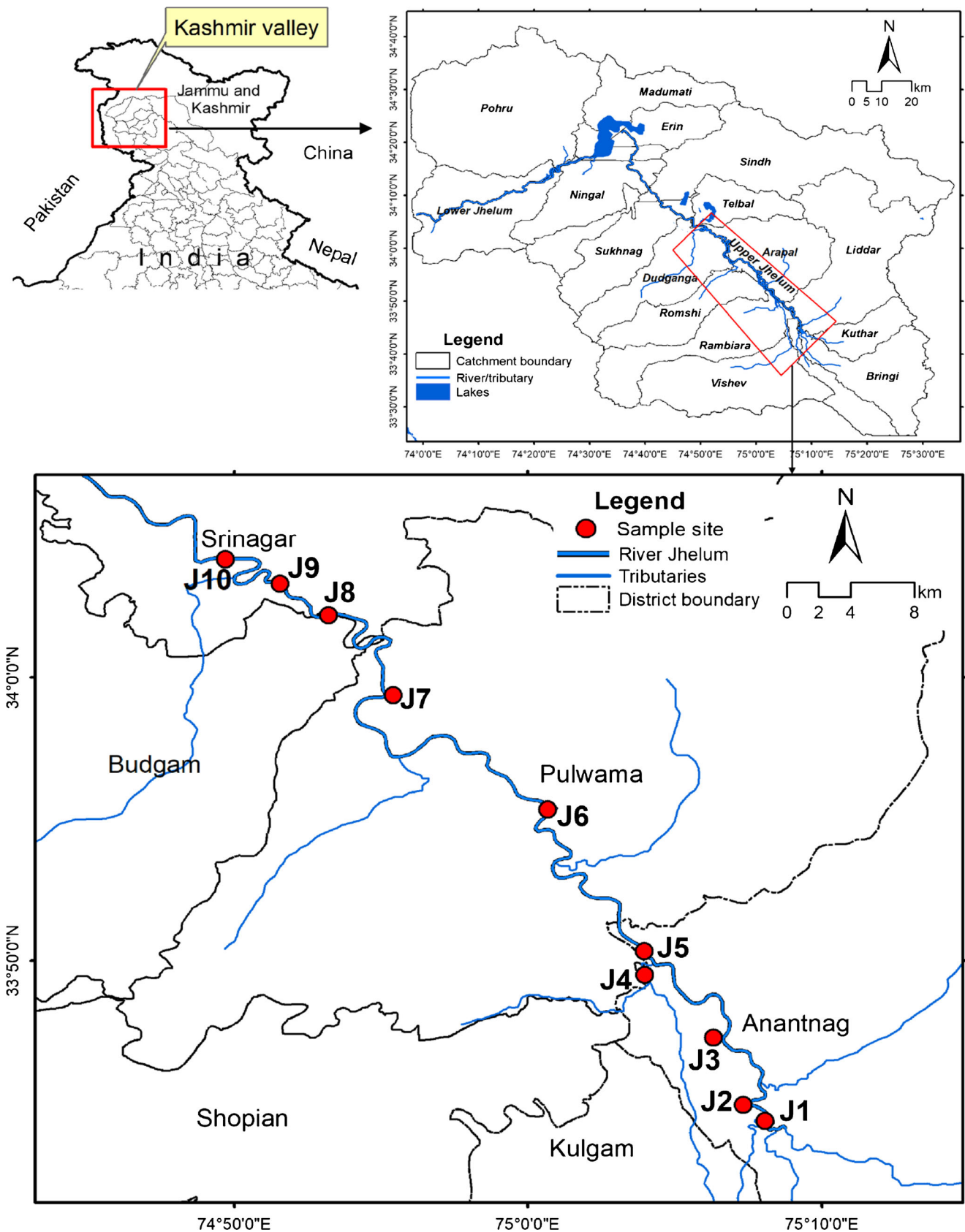


Fig. 1 : Location of the study area and sampling sites.

and J7 from district Pulwama. From Srinagar district, 3 sampling stations were selected such as Panthachowk, Pandrathen, and Zero Bridge designated as J8, J9, and J10 respectively. It is also very imperative to mention that the Jhelum is joined by about 10 major streams from upstream to downstream. The Bringi, Kuthar (Arapath), Liddar, Arapal, Sindh, and Pohru are the right bank streams, whereas left bank streams include the Sandrin, Vishav, Rambhara, Romshi, Dudganga, Sukhnag, Ferozpurhala, and Ningalare. The Bringi and Kuthar (Arapath) join the Jhelum before the sampling stations J1 (Khanabal) and J2 (batengoo), whereas it is joined by the major Lidder stream before sampling station J3 (Bijbehara). The J4 sampling station was selected at the confluence point of Rambhara and Vishav streams at Nayana which later join the Jhelum above the sampling station J5 (Sangam). Before the sampling station J6 (Awantipora) Arapal stream joins the Jhelum, whereas the Romshi stream joins the Jhelum before J7 at Galander. There is no major stream except some highly polluted local streams emerging from the municipal area of Pampore, Panthachowk, and Pandrathen joining the Jhelum before J8 and J9 sampling stations. Before, the sampling station J10 at Zero bridge, the highly polluted waters from world famous Dal Lake enter and join the Jhelum stream. The detailed characteristics of the sampling stations and source of water are given in (Table 1).

In the study area, the climatic conditions are generally temperate in which the month of January remains the coldest, whereas July is the warmest month of the year. The temperature generally varies between a lowest value of  $-5\text{ }^{\circ}\text{C}$  to a highest value of  $> 30\text{ }^{\circ}\text{C}$ . Contrary to temperature the precipitation varies year-round. For example, maximum rains are observed in the summer season, whereas the solid precipitation (snowfall) occurs during the winter season. The occurrence of precipitation with a total annual precipitation of  $\sim 1100\text{ mm}$  is generally higher in the winter season. March receives maximum rainfall, whereas October receives the least. The period from September to November usually remains dry (Mir and Jeelani 2015; Mir et al. 2016). In the Kashmir valley, the river Jhelum is the main drinking water resource for a huge population. Additionally, the sustenance of agriculture and hydropower generation is highly dependent on its runoff. The river also supports a rich reserve of fisheries which is an important source of socioeconomic development.

The Jhelum river basin is characterized by diverse topography and geology. In this basin, the main prominent geomorphological features are *high structural hills*, extensive mounds of *Karewas*, *colluvial fans*, and alluvial-filled *valleys*. Topographically, the basin is a *mountainous* region with low-lying alluvial *plains*, *forests*, and *alpine meadows*. Geologically, a completed stratigraphic sequence of marine *Paleozoics*, *Mesozoics*, and *Cenozoics* has been reported in the valley (Wadia 1975; GSI 1977; Ganju and Khar 1984). The lithology of the area mainly consists the *Silurian Shale*,

*Panjal Trap*, *Muth Quartzite*, *Syringothris Limestone*, *Fenestella Shale*, *Quartzite*, and *Agglomeratic Slate* (Middlemiss 1910), varying in age from *Devonian* to *Upper Permian*, *Triassic*, and *Jurassic* sequences of massive carbonate rocks such as limestones and dolomites, *Quaternary sediments* (Karewa), and recent alluvium (Wadia 1976; Mir et al., 2016). The carbonate lithology is dominantly exposed in the eastern areas, whereas the Panjal Volcanics are dominantly exposed on the western areas of the study area.

## Materials and methods

In this study, the data has been generated for the samples of surface water collected from 10 stations/sites along the upper stretch of the Jhelum River during February to August 2007, characterizing the two seasons that is winter and summer seasons. The samples were collected downstream from Anantnag through Pulwama to Srinagar districts at 10 stations designated as J1, J2, J3, J4, J5, J6, J7, J8, J9, and J10 respectively. Prior to collection of the samples, the bottles were washed with nitric acid and rinsed with distilled water. The samples bottles were airtight having a capacity of 3 l considered sufficient for the sampling. The collected samples have been analyzed at the geochemistry lab, Kashmir University and water laboratory, State Pollution Control Board (SPCB), Srinagar as per the standards of APHA (2005). The pH, water temperature ( $T_{\text{water}}$ ), and air temperature ( $T_{\text{air}}$ ) were analyzed at the sampling sites in the field. Analytical methods used for the estimation of the several physicochemical parameters are given in (Table 2).

## Basic and multivariate statistical analysis

In this study, the software used for basic and multivariate statistical analysis was Statsoft 12 (windows version). Using the statistical analysis tool in the software, the water quality data have been processed to calculate arithmetic mean, standard deviation (SD), skewness, kurtosis, and coefficient of variation (CV). The arithmetic mean and standard deviation, which are a measure of central tendency and dispersion, respectively, are employed for grasping the significance of statistical data. The CV, a statistical measure of the dispersion of data points in a data series around the mean, was computed for studying variability of the variables over the study area. The skewness is the degree of asymmetry in a distribution. A distribution is positively skewed when it has a tail extending out to the right, whereas it is a negatively skewed distribution if the tail is towards left. The skewness for a normal distribution is zero, and any symmetric data should have skewness near zero. If the data are multi-modal, that is, the ions have multi-source, then this may affect the sign of the skewness. Kurtosis reflects the concentration of scores in the center of the distribution, the upper and lower tails and the shoulders of a

**Table 1** Major Land use and land cover characteristics around the sample sites in the study area

Station Id	Place name	Drainage and source of water	Settlement type	Other activities	Major lithology
J1	Khanabal	Sandrin, Bringi, local streams, and major springs begin and contribute to Jhelum river	Highly urbanized and municipal area of Anantnag	High agricultural and horticultural activities in the upper catchment area of Sandrin, Bringi, and Kuthar streams and other local small streams.	Limestones, shales, quartzites, slates, Quaternary sediments
J2	Batango	Kuthar and local streams join Jhelum	Highly urbanized and municipal area of Anantnag	Moderate horticultural and low agricultural activities in surrounding areas	Limestones, shales, slates, Quaternary sediments
J3	Bijbehara	Major Lidder stream and local stream join Jhelum	Highly urbanized and municipal area/town of Anantnag	High agricultural and moderate horticultural activities in surrounding area and high agricultural and horticultural areas in Lidder and other small local streams of the area. Tourism pressure high in Lidder catchment.	Basalts, limestones, shales, slates, Quaternary sediments
J4	Niyana	Rambiara and Vishav major stream confluence each other before joining Jhelum	Rural settlement area of Anantnag	High agricultural and horticultural activities in surrounding area, catchment areas of Rambiara, and Vishav streams. The Lassipora industrial area is located on the Rambiara stream banks.	Basalts, limestones, Quaternary sediments
J5	Sangam	Rambiara and Vishav join Jhelum	Rural settlement area of Anantnag	Moderate agricultural and horticultural activities in the surrounding area.	Limestones, quartzites shales, slates, Quaternary sediments
J6	Awantipora	Arapal and other local streams join Jhelum	Rural settlement area/town of Pulwama	Moderate agricultural and low horticultural activities. High agricultural activities in local stream catchments such as Aripal	Basalts, limestones, Quaternary sediments
J7	Galander	Romshi and other local streams join Jhelum	Rural settlement area Pulwama	High agricultural activities and low horticultural activities in local stream catchments and Romshi catchment.	Basalts, limestones, Quaternary sediments
J8	Panthachowk	Local drainage from surrounding areas drainage into the Jhelum	Urbanized and municipal area of Srinagar and Pulwama (Pampore)	Low horticultural and low agricultural activities in surrounding area but, transportation and local business establishments are located along the river Jhelum banks.	Basalts, limestones, Quaternary sediments
J9	Pandratheren	Local drainage from surrounding areas drainage into the Jhelum	Highly urbanized and municipal area of Srinagar	No horticultural and agricultural activities in surrounding area but, local business and transportation establishments are located along the river Jhelum banks.	Basalts, limestones, Quaternary sediments
J10	Zero bridge Srinagar	Local drainage from surrounding areas and drainage from Dal lake enters into the Jhelum	Highly urbanized and municipal area of Srinagar	No horticultural and agricultural activities in surrounding area, but army cantonment, city hospitals, hotels, and other allied establishments' are located along the river Jhelum banks. Polluted water from Dal enters into Jhelum	Basalts, limestones, Quaternary sediments

distribution. The variance is a measure of the deviations of individual scores from the mean. It is the average of the sum of the squared deviations. Correlation matrix was also developed to study the correlation between individual analyzed water quality parameters.

In order to further assess the water quality of the area, several multivariate statistical techniques (i.e., PCA/FA, cluster analysis (CA)) have been applied. Factor analysis or PCA

is considered a powerful tool to reduce a large number of interrelated variables of a dataset by preserving a significant amount of variability (Koklu et al. 2010). However, the dataset in the present study is not large enough, but still, it contains 17 variables estimated for the two seasons. Further, to understand the underlying factors of the water quality, the FA was used to the normalized datasets separately for two seasons, that is, the summer season and the winter season.

**Table 2** Water quality parameters, abbreviations, analytical techniques, and units as measured during 2007 August (summer) and February (winter) seasons for the upper stretch of the river Jhelum

Water quality parameter	Abbreviation	Instrument/methods	Units
Temperature of air	$T_{\text{air}}$	Thermo meter	°C
Temperature of water	$T_{\text{water}}$	Digital/mercury thermometer	°C
Hydrogen ion concentration	pH	Digital pH meter	pH
Electrical conductivity	EC	Digital conductivity meter	μS/cm
Total hardness	Hd	EDTA titrimetric method	mg/l
Calcium	Ca	EDTA titrimetric method	mg/l
Magnesium	Mg	EDTA titrimetric method	mg/l
Sodium	Na	Flame photometric method	mg/l
Potassium	K	Flame photometric method	mg/l
Total alkalinity	Alkal	Titrimetric method	mg/l
Chloride	Cl	Argentometric titration method	mg/l
Sulfate	SO <sub>4</sub>	Barium chloride method	mg/l
Phosphorous	PO <sub>4</sub>	Perchloric acid method	mg/l
Ammonical nitrogen	NH <sub>3</sub> -N	Phenate spectrophotometric method	mg/l
Dissolved oxygen	DO	Modified winkler's method	mg/l
Chemical oxygen demand	COD	Dichromate reflex method	mg/l
Iron	Fe	Spectrophotometric method	mg/l

Similarly, the CA is a multivariate statistical technique in which the different clusters are formed out of the dataset. It is an exploratory method to identify the closeness between water quality variables. The spatial variability was determined by the hierarchical cluster analysis (HCA) in the form of a dendrogram in which the linkage distance was indicated as  $D_{\text{link}}/D_{\text{max}} \times 100$ , where  $D_{\text{link}}$  gives the linkage distance of a particular case and  $D_{\text{max}}$  gives the maximum linkage distance (Singh et al. 2004).

## Results and discussion

### Physicochemical water quality of the Jhelum River

In this study, the descriptive statistics that include the arithmetic mean, SD, coefficient of skewness, coefficient of kurtosis, and coefficient of variance (CV) of water quality parameters estimated seasonally are mentioned in (Table 3). The high resulting values of standard deviation and skewness help to note the large amplitude for the parameters. The variation reinforces the importance of the spatial analysis of the concentration of these parameters in the river basin.

The CV was computed to study the variability of the parameters over the study area. Among the investigated variables, EC had the highest CV with 85.7% suggesting its dependence with cations and anions present in water. The kurtosis was negative for  $T_{\text{air}}$  and Fe in both seasons, whereas it was positive for hardness, PO<sub>4</sub>, DO, and COD.

The mean air temperature varied from 26.9 °C during the summer season to 11.9°C during the winter season. The mean

water temperature ranged from 20.5 °C during the summer season to 9.1 °C during the winter season. Average pH varied from 7.5 during the summer season to 7.7 during the winter season reflecting the alkaline nature of the Jhelum water. The alkalinity of the surface river water is probably due to the bicarbonate ions which are considered to be the main contributors to the rising pH. In addition, the basic nature of pH can also be as a result of lower organic content in the river water. The average pH is found to be within the permissible WHO range and, therefore, is safe for drinking purposes (WHO, 1999 & 2008). The electrical conductivity (EC) varied from 269 μ/cm during the summer season to 264.5 μ/cm during the winter season. The EC was much lower than a threshold value of 1000 μS/cm on the basis of which the water is called as fresh and unpolluted (Chapman 1992).

The average hardness varied from 167.4 mg/l during the summer season to 138 mg/l during the winter season. The hardness arises as a result of multivalent cations and anions mainly the dissolution of Ca and Mg ions released from carbonate rock formations and other minerals. WHO has categorized the hardness classes from 0–75, 75–150, 150–300, and > 300 as soft, moderately hard, hard, and very hard respectively (WHO 2008). In the Jhelum River, generally, during the summer season, the water is hard, while during the winter season, it is moderately hard. The average concentration of Ca varied from 42.2 mg/l during the summer season to 40.9 mg/l during the winter season. Similarly, the average concentration of Mg varied from 9.8 mg/l during the summer season to 8.7 mg/l during the winter season. The natural source of Ca and Mg ions in the water are mineral rocks such as carbonate rock formations that is the limestone, dolomite, and gypsum which are extensively present in the study

**Table 3** Descriptive statistics of the water quality parameters of the summer season “SS” and the winter season “WS” of the river Jhelum

	Minimum		Maximum		Mean		Standard deviation		Sample variance		Skewness		Kurtosis	
	SS	WS	SS	WS	SS	WS	SS	WS	SS	WS	SS	WS	SS	WS
$T_{\text{air}}$	24.3	10.0	29.2	13.5	26.9	11.9	1.3	1.6	1.8	2.6	-0.3	-0.4	1.0	-2.2
$T_{\text{water}}$	18.4	8.0	22.4	10.5	20.5	9.1	1.3	0.8	1.7	0.7	0.02	0.2	-0.8	-0.5
pH	7.0	7.0	8.0	8.5	7.5	7.7	0.4	0.6	0.2	0.3	0.01	0.04	-1.4	-1.5
EC	210.0	190.0	330.0	390.0	269.0	264.5	43.3	59.1	1876.7	3491.4	-0.2	1.0	-1.5	1.2
Hd	132.0	114.0	190.0	168.0	167.4	138.0	17.3	16.0	298.7	256.0	-0.7	0.4	0.6	0.0
Ca	37.8	32.1	45.6	56.1	42.2	40.9	2.4	7.8	5.8	60.4	-0.2	1.1	-0.4	0.4
Mg	0.3	0.5	19.4	15.6	9.8	8.7	5.6	4.1	31.7	16.7	-0.1	-0.5	-0.1	1.2
Na	2.0	2.0	6.0	5.0	3.5	3.1	1.1	1.0	1.2	1.0	1.3	0.6	2.8	-0.2
K	0.35	0.35	1.00	1.00	0.68	0.71	0.31	0.31	0.10	0.10	0.2	-0.05	-2.5	-2.5
Alkal	95.0	66.0	115.0	94.0	103.0	77.6	7.5	7.8	56.7	61.4	0.9	0.9	-0.8	1.3
Cl	15.0	24.0	25.0	37.0	18.5	30.7	3.0	4.9	8.7	24.0	1.0	-0.1	1.8	-1.3
SO <sub>4</sub>	13.0	18.7	23.0	55.3	17.6	31.0	3.4	11.0	11.7	120.2	0.4	1.2	-0.7	1.8
PO <sub>4</sub>	0.1	0.2	0.3	0.6	0.2	0.3	0.0	0.1	0.0	0.0	0.7	1.8	0.3	3.3
NH <sub>3</sub> -N	0.5	0.4	1.2	1.1	0.7	0.7	0.2	0.2	0.0	0.0	2.4	0.3	6.6	-0.8
DO	2.5	3.5	5.7	8.4	5.1	6.9	1.0	1.5	0.9	2.1	-2.7	-1.5	7.9	3.0
COD	24.2	4.0	40.1	24.0	32.5	12.0	4.7	6.0	21.8	35.6	0.1	0.8	0.1	0.3
Fe	0.24	0.17	0.58	0.66	0.42	0.43	0.12	0.20	0.01	0.04	0.21	-0.28	-1.7	-1.9

area (Mir et al. 2016). The average concentration of Na varied from 3.5 mg/l during the summer season to 3.1 mg/l during the winter season. The sources of these ions are mostly the dissolution of the silicate rocks and soils in the area (Mir et al. 2016). Similarly, the average K values vary from 0.68 mg/l during the summer season to 0.57 mg/l during the winter season. K is naturally released into the water from weathering and erosion of silicate, mica, feldspars, and clay minerals (Krishnamurthi and Bharati 1994) and leaching of plant and animal residues. However, unlike Na ions, K ions possess a weak migratory capacity, so its content normally remains lower in surface waters. Another reason is that the K ions actively participate in biological activities that are used in the absorption by microorganisms and living plants (Sehgal 1991).

Cl varied from 18.5 mg/l during the summer season to 30.7 mg/l during the winter season which were well below the approved limits of Indian (IS) and WHO standards. The mean PO<sub>4</sub> ranged from 0.2 mg/l during the summer season to 0.3 mg/l during the winter season. The phosphate concentration is below the WHO limit of 0.5 mg/ except site J4 which in the winter season indicated a higher concentration (WHO 1963 & 1999). The reason for its higher concentration at site J4 is attributed to the runoff from high agricultural and horticultural activities in the surrounding area and catchment areas of Rambiarra and Vishav streams and discharge of waste detergents. In addition, the Lassipora industrial area may also be the probable source as it is present in a nearby area on the Rambiarra stream banks.

Oxygen plays an important role in almost all the chemical and biological processes of the aquatic ecosystems, such as

and therefore, monitoring of DO is considered essential (Pandey et al. 1993). The DO varied from 5.1 mg/l during the summer season to 6.9 mg/l during the winter season. DO indicate an extent of organic matter pollution load, the degradation of organic materials and the intensity of self-purification capacity of the aquatic bodies. In the present study area, the oxygen holding capacities of water decreased at high temperature during the summer season, and thus, DO declines, whereas at lower temperatures during the winter season, oxygen remains dissolved in water thus increasing its DO content (Pandey et al. 1993; Spasojevic et al. 2005).

The average COD varied from 32.5 mg/l during the summer season to 12 mg/l during the winter season. COD gives an estimate of the extent of organic and non-biodegradable pollution in either rivers or lakes. In the present area, the COD levels did not exceed the Indian standards (IS 1983). The average concentration of Fe varied 0.42 mg/l during the summer season to 0.43 mg/l in the winter season. As per the Secondary Maximum Contaminant Level (SMCL) standards and classification, an iron content of 0.3 mg/l is suggested safe for drinking water (EPA 2017). In this area, the Fe content is observed to be higher than the prescribed limit.

### Spatio-temporal variations of the water quality of Jhelum River

The spatio-temporal variation of water quality of Jhelum River is shown in (Fig. 2a–q).  $T_{\text{air}}$ ,  $T_{\text{water}}$ , EC, alkalinity, PO<sub>4</sub>, and COD indicated a decreasing trend down the stream while Na,

K, and  $\text{SO}_4$  ions revealed an increasing trend. The abrupt rise in  $T_{\text{water}}$  at certain sites is attributed to the addition of domestic sewage (Fig. 2b). The association of fluctuation in water temperature with the addition of commercial and domestic sewage overload pattern is also reported by Palharya and Malviya (1988) and Kaur et al. (2003). The EC indicating the amount of dissolved ions and degree of mineralization in water is relatively higher at J1 and J10 than the other 8 sites between J2 to J9. The higher EC at the initial sites is ascribed to the higher discharge of municipal and household waste effluents entering into the river around J1 and J2 sites which are located in urbanized areas of district Anantnag. However, a subsequent decline after J2 till J9 in EC may be probably caused by the dilution effect of the direct runoff and input of waters from less polluted side streams.

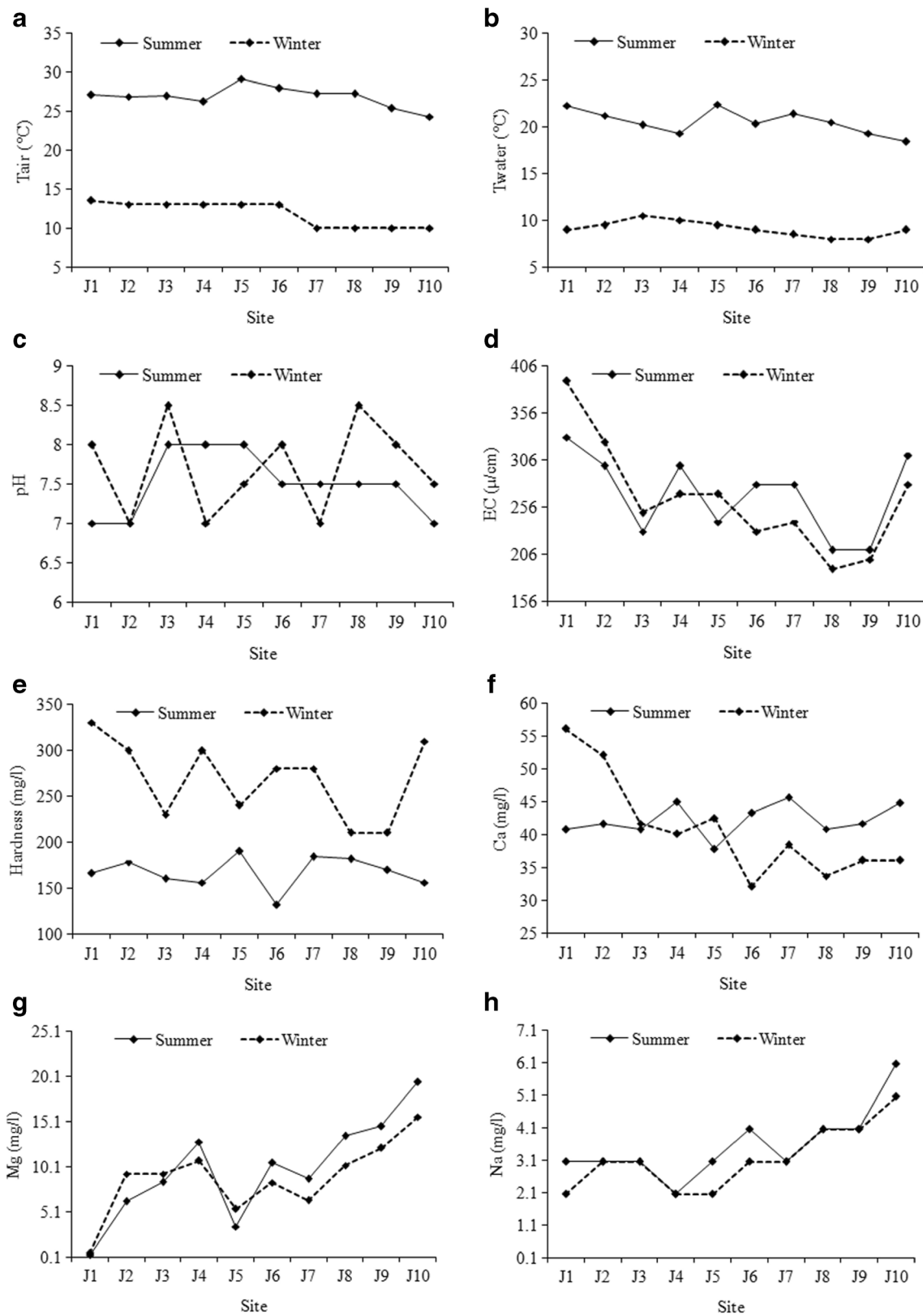
The Ca, Mg, DO, and Fe indicated an increasing trend downstream during the winter season and vice versa. Similarly, cations revealed a rising pattern from J5 upstream site. The concentration of Mg also indicated an abrupt decrease from site J4 to J5 and then rises again and maintains the increasing pattern afterwards. In general, the natural source of Ca and Mg is silicate and carbonate rocks such as Panjal Volcanics, dolomite, and gypsum (Mir and Jeelani; Mir et al. 2016). However, the increase in Ca and Mg downstream in the summer season reflects the higher contribution from agricultural and domestic wastes. Contrary to this, the Na during the summer season declines to lower values from J3 to J4 and then rises up to J6. From J6 to J7, the Na again slightly decreases and then rises and maintains the rising pattern afterwards. The Na is normally released from the weathering of silicate rocks and soils. However, the high trend downstream is suggested to be due to the influence of agricultural, domestic, and municipal waste and sewage being released into the river. In the case of K, the J6, J7, J10 sites revealed a concentration of 1 mg/l which is probably attributed to the contribution from leaching of plant and animal residues from the surrounding areas. Similarly, the Fe from J1 to J3 decreases gradually and then rises up to J4. From J6 to J8, the Fe declines in the summer season and then rises again slightly afterwards. However, during the winter season, after J3, the Fe rises and maintains a similar pattern systemically afterwards. The naturally occurring common iron minerals are magnetite, hematite, goethite, and siderite. Chemical weathering processes of natural rocks release the Fe into waters. In addition, at certain sites, the higher concentration of Fe may also be attributed to the fertilizers and pesticides. The Cl and  $\text{NH}_3\text{-N}$  revealed rising trends in the summer season and mixed nature during the winter season. The Cl is generally present in the form of NaCl, CaCl, KCl, and MgCl in the environment. The Cl ion and its salts are mobile and therefore are easily released into the riverine systems in proximity to the source (Weast 1986). The  $\text{NH}_3\text{-N}$  is often found in different waste products of sewage, liquid manure, organic waste

products, etc. The higher value of  $\text{NH}_3\text{-N}$  is reflected through the higher trends downstream. Nevertheless, few analyzed elements at certain sites exhibited either a high concentration (positive peak) or a low concentration (negative peak) during either of the seasons as shown in Fig. 2a–q.

The elements exhibited a heterogeneous pattern temporally. For instance, the EC is higher at J4 and J6–J10 during the summer season than during the winter season which is attributed to the discharge of agricultural wastes and domestic wastes. The summer season is the main cultivation period of the area (Mir et al. 2016). The pH is higher at J1, J3, J6, and J8–J10 during the winter season. The change in pH values is closely connected to the photosynthetic activities of the plants and organic matter decomposition between the two seasons. In addition, the Ca, Mg, Na, and K ions at most of the sites revealed higher values which are attributed to municipal and domestic waste discharge into the river. The application of potassium-containing fertilizers and its other products are sources of higher concentration downstream especially in the summer season. Similarly, the alkalinity and Cl is significantly higher in the summer season than in the winter season which indicates the significant influence of anthropogenic effects that is through the release of untreated domestic sewage and municipal waste and the effect of agricultural activities. The  $\text{SO}_4$  and  $\text{PO}_4$  concentration is higher during the winter season as compared with the summer season and thereby indicates the influence of dilution during high flow period. A vivid higher concentration of Fe is observed at initial five sites from J1 to J5 during the summer season than during the winter season. Commonly, the source of iron may be the iron minerals such as magnetite, hematite, goethite, and siderite and a part of higher values downstream may also be acquired from pesticides and fertilizers as the summer season is the peak season for agricultural and horticultural activities in the area. The higher COD is observed during the summer season which reflected the depletion of oxygen as a result of the higher photosynthetic decay of the organic wastes in the river. Similarly, the higher concentration of DO during the summer season in the Jhelum River indicates significant anthropogenic inputs in addition to the flat flow of the river resulting in decreasing DO levels. The high DO also indicates the extent of organic matter pollution load, the degradation of organic materials, and the intensity of self-purification capacity of the aquatic bodies. However, the high DO in the summer season is in contradiction to Rather et al.'s (2016) results who reported a higher concentration in the winter season and attributed that to the low winter temperatures that enhance the dissolution of gasses in water.

Overall, from the results, it is found that most of the physiochemical parameters revealed higher values in the summer season as compared with the winter season. The higher concentration is attributed to the flushing of higher pollutants from the agricultural fields due to the higher amounts of





**Fig. 2** Spatial-temporal variation of water quality parameters during summer and winter seasons downstream of river Jhelum.

utilized water into the river. In the Kashmir valley, the summer season is the peak season of the agricultural and horticultural

activities during which a higher application of synthetic fertilizers is carried out.

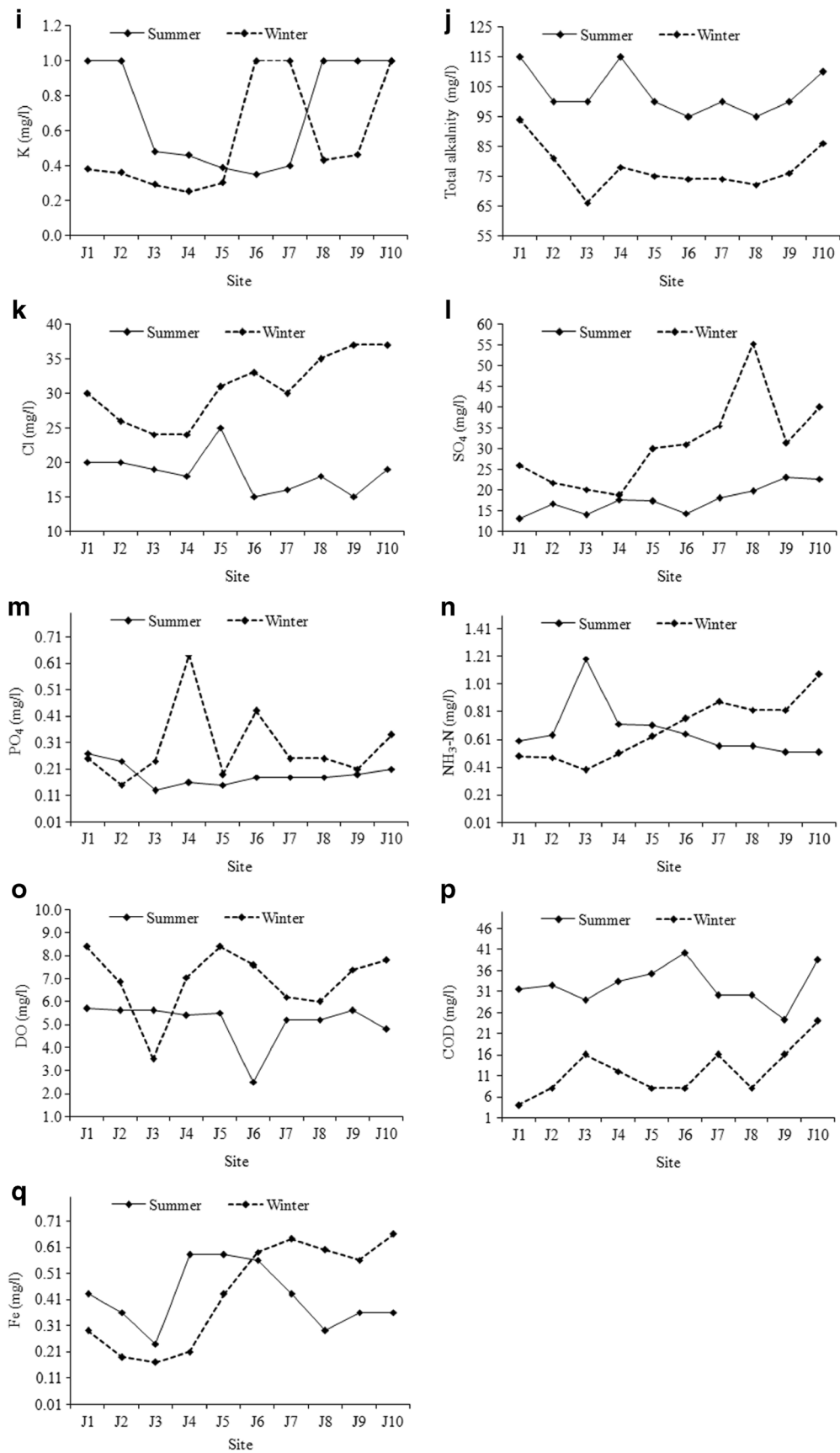


Fig. 2 (continued)

## Correlation of water quality parameters

A detailed correlation matrix of physicochemical parameters of Jhelum River studied for two seasons is given in (Table 4). The  $T_{\text{air}}$  bears a positive and strong correlation with  $T_{\text{water}}$  (0.81–0.74) during both seasons.  $T_{\text{water}}$  has relatively modest negative correlation with Na during both seasons. The correlation of  $T_{\text{water}}$  with  $\text{SO}_4$  increases from a modestly negative (– 0.61) correlation in summer season to a strong negative correlation (– 0.76) in the winter season. In addition, it has a strong negative correlation with Cl (– 0.82) and  $\text{NH}_3\text{-N}$  (– 0.70) in the winter season. However, during the summer season, the  $T_{\text{water}}$  has a fair negative correlation with Ca and a strong negative correlation with Mg (–0.93) whereas; a positive and weak correlation with hardness and Cl. Overall from these observations it is inferred that the increase in positive correlations with the organic-related parameters (i.e., COD and  $\text{NH}_3\text{-N}$ ) was a result of a faster decay of organic matter due to the higher temperature in summer. However, a negative increase in correlations between the mineral-related parameters (i.e., Ca, Mg and  $\text{SO}_4$ ) could be attributed to the dilution effect during the wet summer season. The pH during the summer season, bears a modest negative correlation with EC and Na whereas; it has a negative strong correlation with K (– 0.73) and  $\text{PO}_4$  (– 0.91). It has feeble and positive correlation with  $\text{NH}_3\text{-N}$  in the summer season; this can be associated with relatively high nitrification rates due to the high temperature in the summer season. The EC has a strong and positive correlation with total alkalinity (0.69) in the summer season which decreases to higher negative strength (– 0.79) during the winter season. In the summer season, EC has a positive correlation with  $\text{PO}_4$  and COD which changes to modest negative correlation in the winter season. During the winter season, it has a relatively weak correlation with Mg and  $\text{SO}_4$  but a positive correlation with hardness. It has a strong positive correlation with Ca (0.90) in the winter season. In general, alkalinity always indicated a good correlation with EC during both the seasons. The correlation results overall reflected the influence of dilution effect on most of the major ions due to higher discharge during the summer season. However, its positive correlation with the Ca, Mg and alkalinity in the winter season reflected the higher concentration of these ions during which base flow is the main contributor of water to the river flow.

The hardness bears a weak but positive correlation with Ca in the winter season and a strong positive correlation with DO (0.71) in the summer season. The Ca has a feeble positive correlation with Mg in the summer season which changes to fairly strong and negative correlation (– 0.62) in the winter season. The correlation of Na and  $\text{SO}_4$  reveals a similar pattern i.e., a change from positive to negative nature. Similarly, the Cl (– 0.66) in summer season and  $\text{NH}_3\text{-N}$  (– 0.66) in the winter season indicated negative correlation with Mg with a significant variation between the two seasons. However, the Mg has a positive correlation with total alkalinity during the

winter season. The Mg has a positive and strong correlation with Na (0.64–0.77) during both the seasons. Mg has a strong positive correlation with  $\text{SO}_4$  (0.77) during the summer season and COD (0.74) during winter season whereas, it has a weak and negative correlation with Cl in the summer season and positive correlation with  $\text{NH}_3\text{-N}$  in the winter season. Total alkalinity has a strong positive correlation with DO (0.70) during the winter season. Overall, the content of Mg in water increases the hardness of the water and has a positive effect on algal growth and DO production. Na in the winter season has a strong and positive correlation with  $\text{SO}_4$  (0.62), COD (0.67) and weak positive correlation with K. The correlation of Na with Cl and  $\text{NH}_3\text{-N}$  changes from a weak negative correlation to positive and strong correlation (i.e., 0.69 and 0.75) in the winter season. The positive correlation of Na with the other organic compounds reflected the contribution from domestic, municipal and agricultural sources during the studied seasons. Na is partly contributed from the silicate rocks also. The K is also contributed from the anthropogenic sources which are indicated by its strong and positive correlation with  $\text{NH}_3\text{-N}$  (0.77) and a weak correlation Cl during the winter season. During the summer season, it bears a strong and positive correlation with  $\text{PO}_4$  (0.70). The Cl also bears a strong and positive correlation with the  $\text{SO}_4$  (0.75) and  $\text{NH}_3\text{-N}$  (0.84) during the winter season. The  $\text{SO}_4$  has a negative and weak correlation with  $\text{NH}_3\text{-N}$  during summer season which changes to strong positive correlation (0.74) during the winter season. The  $\text{PO}_4$  has a negative and weak correlation with  $\text{NH}_3\text{-N}$  during the summer season. The  $\text{NH}_3\text{-N}$  has a positive but weak correlation with COD during the winter season. The DO has a significant and negative correlation with COD during the summer season. Fe in the summer season has a negative correlation with K which changes to positive strong correlation (0.77) during the summer season. In the winter season, the Fe has a negative strong correlation with  $T_{\text{water}}$  (– 0.78) and Ca (– 0.69). However, the Fe bears a strong positive correlation with Cl (0.87),  $\text{SO}_4$  (0.80) and  $\text{NH}_3\text{-N}$  (0.95). Fe and  $\text{SO}_4$  are mainly contributed from the crustal rocks such as Panjal Volcanics and Carbonate rock formations e.g., limestones containing pyrites in the area.

## Principal component analysis

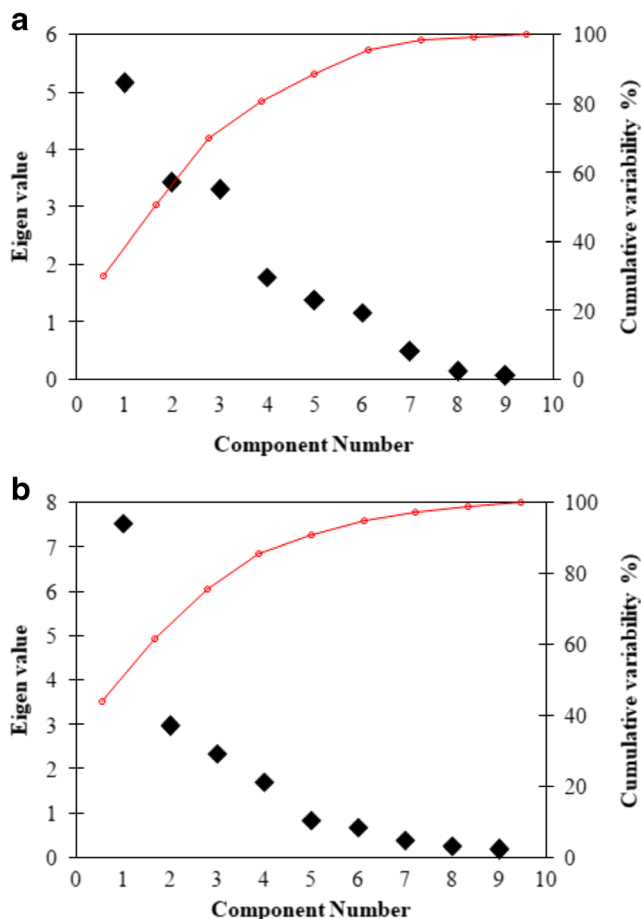
To determine the pollution factors that have an influence on each of the identified regions, PCA/FA of standardized log-transformed datasets was carried out separately for summer and winter seasons. This technique utilizes the eigen values to determine the number of principal components (PCs) to be retained for further analysis. In this study, the scree plots were employed to determine the number of PCs that can be retained to understand the underlying structure of parameters for two seasons (Fig. 3a, b). As seen, the scree plots for the used eigen values indicated a distinct change in slope after the sixth eigen

**Table 4** Correlation matrix between the water quality parameters during the summer season (normal font) and the winter season (italic font) of the river Jhelum

Variables	<i>T<sub>air</sub></i>	<i>T<sub>water</sub></i>	pH	EC	Hd	Ca	Mg	Na	K	Alkal	Cl	SO <sub>4</sub>	PO <sub>4</sub>	NH <sub>3</sub> -N	DO	COD	Fe	
<i>T<sub>air</sub></i>	1.00																	
<i>T<sub>water</sub></i>	<i>1.00</i>	1.00																
pH	0.81	<i>1.00</i>	1.00															
EC	0.74	<i>1.00</i>	<i>1.00</i>	1.00														
Hd	0.42	0.00	1.00															
Ca	-0.05	-0.16	<i>1.00</i>	1.00														
Mg	-0.19	0.08	-0.53	1.00														
Na	0.60	0.39	-0.31	<i>1.00</i>	1.00													
K	0.26	0.52	0.05	-0.32	1.00													
Alkal	0.14	0.34	-0.32	0.53	<i>1.00</i>	1.00												
Cl	-0.57	-0.56	-0.21	0.45	-0.42	1.00												
SO <sub>4</sub>	0.58	0.35	-0.23	0.90	0.56	<i>1.00</i>	1.00											
PO <sub>4</sub>	-0.73	-0.93	-0.03	-0.21	-0.32	0.56	1.00											
NH <sub>3</sub> -N	-0.54	-0.08	-0.03	-0.54	0.30	-0.62	<i>1.00</i>											
DO	-0.53	-0.52	-0.50	-0.04	-0.24	0.18	0.64	1.00										
COD	-0.79	-0.50	0.25	-0.46	0.15	-0.54	0.77	<i>1.00</i>										
Fe	-0.57	-0.18	-0.73	0.06	0.19	-0.11	0.20	0.45	1.00									
	-0.48	-0.40	-0.15	-0.22	-0.35	-0.49	0.23	0.50	<i>1.00</i>									
	-0.43	-0.13	-0.18	0.69	-0.17	0.28	-0.06	-0.14	0.19	1.00								
	0.14	-0.13	-0.28	0.79	0.44	0.59	-0.26	-0.07	0.07	<i>1.00</i>								
	0.42	0.52	0.14	0.09	0.49	-0.66	-0.51	-0.19	-0.02	0.20	1.00							
	-0.69	-0.82	0.29	-0.38	-0.28	-0.51	0.32	0.69	0.51	0.17	<i>1.00</i>							
	-0.63	-0.61	-0.13	-0.32	0.24	0.25	0.77	0.58	0.42	-0.05	-0.21	1.00						
	-0.75	-0.76	0.34	-0.50	-0.40	-0.54	0.24	0.62	0.40	-0.09	0.75	<i>1.00</i>						
	-0.26	0.22	-0.91	0.63	0.02	0.06	-0.25	0.18	0.70	0.38	0.00	-0.06	1.00					
	0.18	0.28	-0.23	-0.08	-0.15	-0.33	0.24	-0.18	0.11	0.03	-0.21	-0.20	<i>1.00</i>					
	0.26	0.05	0.59	-0.23	-0.17	-0.28	-0.26	-0.40	-0.46	-0.08	0.23	-0.55	-0.57	1.00				
	-0.84	-0.70	-0.05	-0.46	-0.27	-0.66	0.50	0.75	0.77	0.06	0.84	0.74	0.01	<i>1.00</i>				
	-0.16	0.20	0.06	-0.12	0.71	-0.31	-0.25	-0.35	0.37	0.35	0.44	0.16	0.10	0.14	1.00			
	0.08	-0.33	-0.35	0.37	-0.01	0.17	-0.21	-0.14	0.16	0.70	0.44	0.07	0.10	0.29	<i>1.00</i>			
	0.16	-0.05	-0.15	0.53	-0.49	0.20	0.08	0.31	-0.30	0.11	0.21	-0.20	0.05	-0.11	-0.68	1.00		
	-0.61	0.00	-0.13	-0.33	0.21	-0.46	0.74	0.67	0.44	-0.15	0.26	0.12	0.10	0.56	-0.27	<i>1.00</i>		
	0.41	0.22	0.28	0.35	-0.20	0.09	-0.23	-0.33	-0.57	0.24	0.16	-0.19	-0.09	-0.23	-0.38	0.53	1.00	
	-0.78	-0.78	0.10	-0.54	-0.53	-0.69	0.29	0.62	0.77	-0.05	0.87	0.80	-0.06	0.95	0.28	0.36	<i>1.00</i>	

value in the case of the summer season and fourth eigen value in the case of the winter season (Fig. 3). Overall, the FA of the selected two seasons resulted in 6 variance factors (VFs) for the summer season and 4 factors for the winter season, respectively, with eigen values > 1 that explained 95.7% and 85.8% of the total variance in the dataset (Table 5).

The PCA results in the projection of the original variables of the dataset on a subspace of PCs (principal components) defined as component loadings. The component loadings coincide with the correlation coefficients between PCs and original variables. These component loadings are used to find out the relative importance of each variable (or parameter in this study) against other variables in a PC. It is notable that the component loadings do not reflect the importance of the component itself. In this study, Figs. 4 and 5 represents the sampling sites defined by their scores on component 1 versus 2. Overall, three independent clusters can be defined, highlighting a very clear spatial discrimination. The first cluster is formed by samples collected from site J1, J2 and J5, the second from sites J3, J4, J6 and J7 delete, and the third from sites J8, J9, and J10. According to the variable loadings responsible for this discrimination, the first cluster is discriminated due to



**Fig. 3** Scree plot of the eigen values of principal components in **a** summer season and **b** winter season of the river Jhelum

high levels of some mineral components (Cl, Hd, DO) likely from a natural origin. Cluster 2 is partially affected by PC1 and resides on the negative side of PC2 and is mainly affected by organic mineral components (COD, Fe,  $\text{NH}_4\text{-N}$ , pH). The cluster 3 is subjected to mineral component inputs mainly related to high anthropogenic mineral discharges ( $\text{PO}_4$ ,  $\text{SO}_4$ , K, Na, Alkal) from the urbanized area and cities and agricultural inputs around the river. However, during the winter season, there is minor seasonal discrimination and spatial variation in the clustering. During the winter season, the sites J3, J4, J6, and J7 also reflect the imprint of anthropogenic mineral component.

In addition, the detailed results of FA which include the loadings, variance contribution rate of each variance factor (VF) and cumulative variance contribution rate are given in (Table 5). Additionally, the relationships among the parameters; their smaller distance, stronger correlation between the parameters (Qu and Kelderman 2001) of the two studied seasons are shown in (Fig. 5). The techniques of PCA and FA have been employed widely to understand the water quality parameters and its spatio-temporal variations (Singh et al. 2004). Previously, Liu et al. (2003) have categorized the determined factor loadings as strong, moderate and weak depending up on the absolute loading values of > 0.75, 0.75–0.50, and 0.5–0.3. Overall, the positive value of loadings defines the important inputs whereas; the negative values correspond to low inputs.

In this study, among the six determined VFs for summer season, VF1 describes 30.4% of the total variance. The F1 bears a strong negative loading on  $T_{\text{air}}$ ,  $T_{\text{water}}$ , moderate negative loading of pH, Cl and  $\text{NH}_3\text{-N}$ . In addition, it possesses a strong positive loading of Mg and moderate positive loading on Ca, Na, K and  $\text{SO}_4$ . This component has a major contribution of natural inputs (e.g., Mg and Ca) over the physical parameters (i.e., temperature) and anthropogenic and agricultural inputs (e.g.,  $\text{NH}_3\text{-N}$ ). The agricultural drainage water is considered to be the common source of Mg ions (Boyacıoğlu 2006). In addition, the dissolution of volcanics, gypsum and limestone soils in the river catchments may be also a major source of minerals in the river water. This factor represents the mineral pollution. It is also notable that the minerals may be also coming from the different grades of alluvial soils (i.e., gravel, sand, clay, and silt) due to continuous sand mining activities in sites 2 and 3. During the winter season, almost similar component loadings were observed with minor variation. For instance, during the winter season, among the four determined VFs for the winter season, VF1 described the 44.3% of the total variance. The F1 bears a negative strong loading on  $T_{\text{air}}$ , Ca and moderate loading on  $T_{\text{water}}$  and EC. In addition, it possesses a positive strong loading on Na, Cl,  $\text{SO}_4$ ,  $\text{NH}_3\text{-N}$ , Fe and moderate loading on Mg, K, and COD. Overall, this factor represented mineral pollution, which can be defined as a mineral component of the river water and

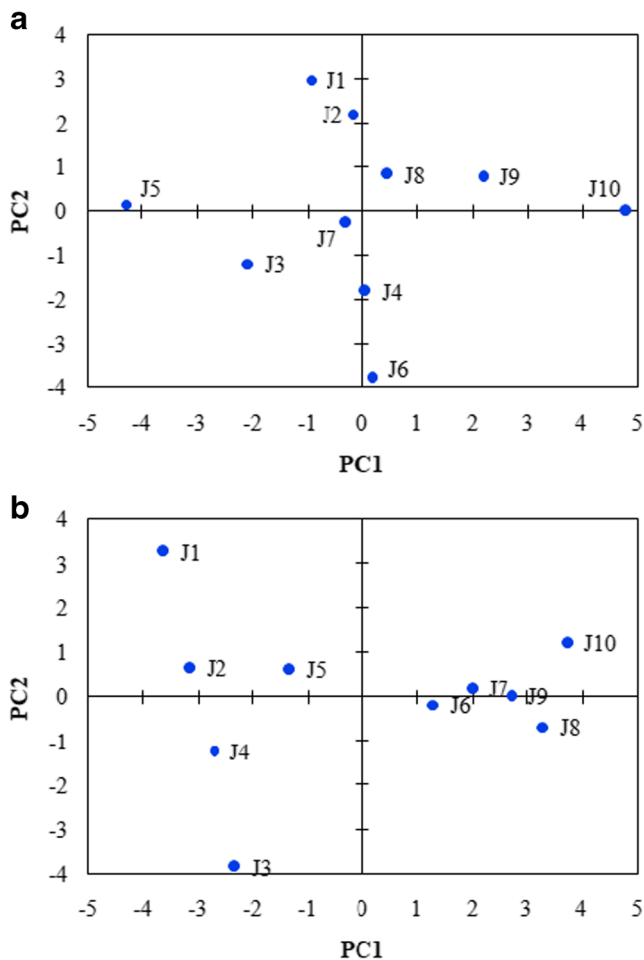
**Table 5** Loadings of 17 experimental variables on significant variance factors (VFs) for the summer season and the winter season of the river Jhelum. Note: The values in italic indicate the significant loadings.

Parameters	Summer						Winter			
	F1	F2	F3	F4	F5	F6	F1	F2	F3	F4
$T_{\text{air}}$	<i>-0.891</i>	-0.133	0.132	-0.387	0.020	-0.105	<i>-0.892</i>	-0.020	-0.156	0.201
$T_{\text{water}}$	<i>-0.790</i>	0.402	0.285	-0.265	-0.027	-0.183	<i>-0.732</i>	-0.437	0.297	0.179
pH	<i>-0.566</i>	<i>-0.560</i>	-0.455	0.290	0.234	0.010	0.203	-0.285	<i>-0.515</i>	-0.474
EC	0.196	0.129	<i>0.904</i>	0.294	0.008	0.033	<i>-0.708</i>	<i>0.592</i>	0.239	-0.073
Hardness	-0.365	<i>0.646</i>	-0.393	-0.108	0.389	-0.188	-0.380	0.124	<i>0.781</i>	-0.434
Ca	<i>0.639</i>	-0.374	0.247	0.332	0.016	-0.380	<i>-0.807</i>	0.442	0.100	-0.335
Mg	<i>0.814</i>	-0.369	-0.373	0.018	0.188	0.085	<i>0.569</i>	-0.392	<i>0.628</i>	-0.027
Na	<i>0.738</i>	-0.018	-0.068	-0.466	0.040	0.399	<i>0.817</i>	-0.054	0.387	-0.355
K	<i>0.552</i>	<i>0.753</i>	-0.083	-0.113	-0.139	0.136	<i>0.661</i>	0.222	0.128	0.382
Alkal	0.195	0.250	0.492	<i>0.723</i>	0.222	0.151	-0.216	<i>0.876</i>	0.303	-0.018
Cl	<i>-0.565</i>	0.384	0.122	0.001	0.411	<i>0.581</i>	<i>0.838</i>	0.413	-0.107	-0.139
SO <sub>4</sub>	<i>0.671</i>	0.109	-0.486	-0.102	<i>0.527</i>	-0.049	<i>0.812</i>	0.167	-0.291	-0.205
PO <sub>4</sub>	0.335	<i>0.683</i>	<i>0.587</i>	-0.126	-0.189	-0.112	-0.047	-0.200	0.200	<i>0.795</i>
NH <sub>3</sub> -N	<i>-0.528</i>	-0.311	-0.263	0.406	-0.435	0.427	<i>0.934</i>	0.264	0.162	0.134
DO	-0.203	<i>0.724</i>	-0.376	<i>0.508</i>	0.167	0.033	0.038	<i>0.847</i>	-0.005	0.321
COD	0.085	-0.446	<i>0.674</i>	-0.287	0.231	0.407	<i>0.534</i>	-0.287	<i>0.684</i>	0.009
Fe	-0.291	-0.398	<i>0.564</i>	-0.010	<i>0.560</i>	-0.217	<i>0.931</i>	0.253	-0.155	0.158
Eigen value	5.2	3.4	3.3	1.8	1.4	1.2	7.5	3.0	2.4	1.7
Variability (%)	30.4	20.2	19.5	10.6	8.1	7.0	44.3	17.5	13.9	10.1
Cumulative%	30.4	50.6	70.1	80.6	88.8	95.7	44.3	61.8	75.7	85.8

anthropogenic facilities. In this area, the Mg and Na indicated the cases of soil weathering, erosion (seasonal effect) and anthropogenic sources of pollution. Moreover, the presence of NH<sub>3</sub>-N represents the nutrient-related parameters that may probably be due to the input from sewage and influents from municipal wastes. Results showed that VF2 during summer season explained 20.2% of the total variance of the data. The F2 bears a moderate negative loading on pH and strong positive loading on K, moderate strong positive loading on hardness, PO<sub>4</sub> and DO. This component finds out and distinguishes the importance of anthropogenic and inorganic pollutants over the natural inputs (e.g., pH). A similar pattern on loading is observed during the winter season. For instance, the VF2 during winter season explained 17.5% of the total variance during the winter season.

The F2 bears a positive strong loading on alkalinity, DO and moderate loading on EC reflecting the influence of the mineral and organic-related parameters on the water quality during the winter season. The F3 explained the 19.5% of the total variance. This factor possesses a strong positive loading of EC and moderate positive loading of PO<sub>4</sub>, COD and Fe. Thus during the summer season, the F1 indicated a major contribution of natural pollution. The EC is considered an important index of natural pollution. This factor indicated that the mineral and inorganic-related parameters in the

summer season are affecting the water quality of the river. However, during the winter season, the F3 explained the 13.9% of the total variance of the data. This factor possesses moderate negative loading of pH whereas; a positive strong loading on hardness and moderate loading on Mg and COD. The hardness of the water indicated the influence of soil leaching and erosion (seasonal effect). During the winter season, this factor represented mineral pollution, which was explained as a mineral component of the river and anthropogenic facilities. The hardness and Mg revealed effects of soil weathering, erosion (seasonal effect), and anthropogenic sources of pollution in this area. Similarly, COD is considered an index of organic pollution (Kazi et al. 2009). In this area, the organic pollution attributed to the influence of point sources of pollution such as domestic wastewater and industrial effluents (Juahir et al. 2011). However, due to the nonexistence of industrial sector in the area, domestic pollution is considered to be the significant factor responsible for organic pollution. Similarly, COD was related to anthropogenic point sources of pollution. For instance, the municipal sewage and limited industrial effluent are the dominant anthropogenic activities in the area (Wang et al. 2007) in downstream sites from J5–J10. The VF4 described 10.6% of the total variance and bears a moderate positive loading on alkalinity and DO.

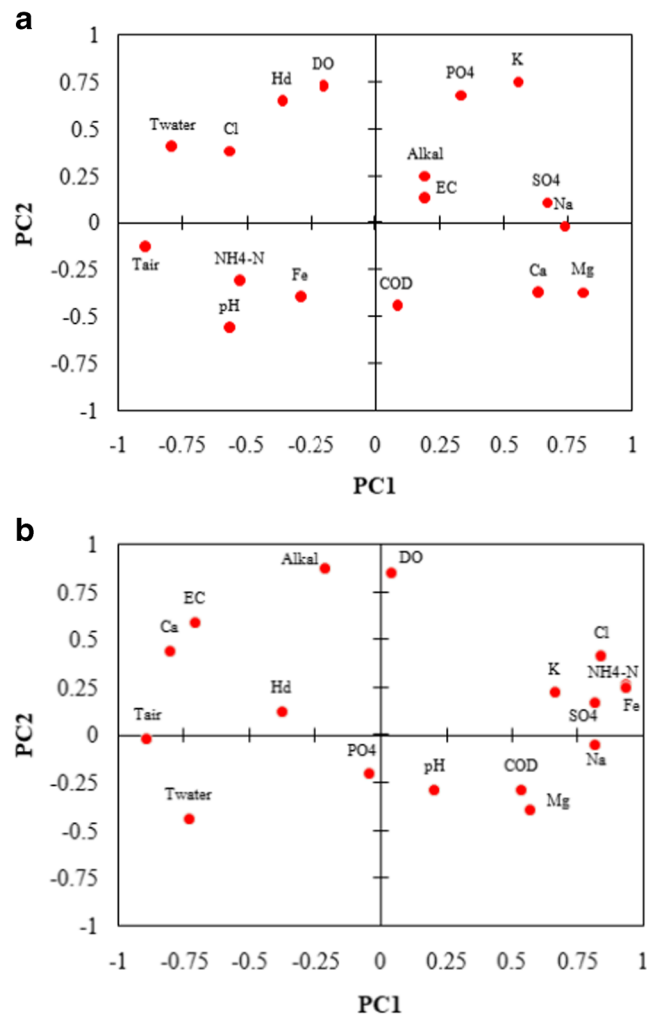


**Fig. 4** Plots of the first two principal component loadings PC1 versus PC2 **a** summer season and **b** winter season for all analyzed sampling sites of river Jhelum

Overall, this factor represented mineral and organic related pollution. In general, the BOD and COD are considered indexes of organic pollution factors (Kazi et al. 2009). During the winter season, the F4 described 10.1% of the total variance and possess strong positive loading on PO<sub>4</sub> which reflected the inorganic related pollution during the winter season. The VF5 described 8.1% of the total variance and had moderate positive loading on SO<sub>4</sub> and Fe. The VF6 explained 7.0% of the total variance and possess moderate positive loading on Cl. The factors 5 and 6 during the summer season reflected the effect of domestic wastewater, agricultural activities, and municipal effluents. Overall, in this study, the employed PCA produced a number of principal components which is in concert with previous studies (e.g., Mir et al. 2016; Khan et al. 2016).

**Hierarchical agglomerative cluster analysis**

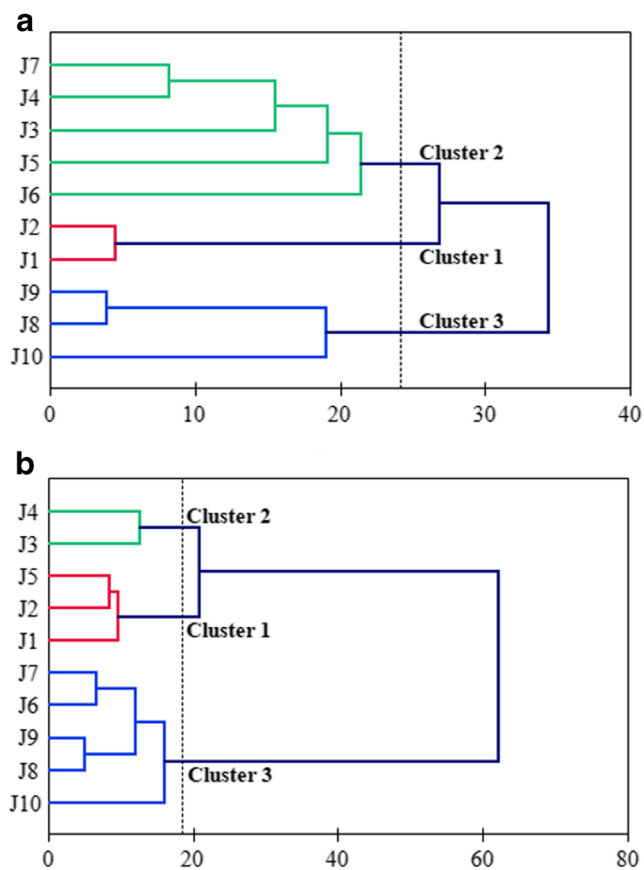
The cluster analysis was applied on standardized log-transformed datasets of summer and winter seasons of the



**Fig. 5** Plots of the first two principal component loadings PC1 versus PC2 **a** summer season and **b** winter season for all analyzed parameters of river Jhelum

river. The analysis detected the spatial and temporal similarity in groups between the sampling stations for two studied seasons. In this technique, squared Euclidean distances are used as a measure of similarity. Based on the 17 variables, the CA produced a dendrogram and grouped the 10 sampling stations/sites into three groups or clusters during both the seasons. However, there is a significant change in grouping the sites from summer season to winter season as shown in (Fig. 6).

During the summer season, in cluster 1, sites 1 and 2 were grouped together with similar characteristics representing the upper stretch of Jhelum River from Khanabal to Batango. The group 2 consisted of J7, J4, J3, J5 and J6 sites representing the middle stretch of the Jhelum River from Bijbehara to Galander. The cluster 3 consisted of three downstream sites such as J9, J8 and J10 representing lower stretch of river from Panthachowk to Zero Bridge. During winter season, the cluster 1 consisted of three upstream J1, J2 and J5 sites representing upper stretch of main river Jhelum from



**Fig. 6** Dendrogram based on hierarchical clustering (Ward's method) for 10 stations in downstream during **a** summer season and **b** winter season of river Jhelum

Khanabal to Batango. The group 2 consisted of J4 and J3 sites representing the middle stretch of the Jhelum River from Bijbehara to Sangam (upstream). However, it is important to note that the J4 is a sampling station collected within the Rambiar-Vishav tributary before joining the main Jhelum River. The site J5 belongs to middle stretch of the river and represents Sangam station within main Jhelum River (downstream). The cluster 3 consisted of five downstream sites such as J7, J6, J9, J8 and J10 representing the lower stretch of the river from Awnatipora to Zero Bridge.

In general, the three clusters probably correspond to the sources of low pollution (LP) and high-pollution (HP) areas controlled by almost similar sites along the river stretch with certain variations during the two seasons respectively. For instance, during the summer season, an internal analysis of cluster 2 indicated that sampling stations J7 and J4 had similar features compared with site J3 which had similar features compared with J5. Sites J5 and J3 had similar features compared with site J6. However, during the winter season, the similarity has been prevalent for sites J3 and J4 only in cluster 2. During the winter season, there was an obvious change in grouping and the sites J5 and J2 had similar features compared with J1 in cluster 1

during the winter season. The omission of the sites J3 and J4 in cluster 1 in the winter season is probably due to the introducing of water of different nature from Lidder and Rambiar-Vishav streams. The site J5 is taken within the main Jhelum river downstream of J4 and J3 thereby indicating a complete mixing of the water from these tributary streams and preserving/representing the initial nature of the water as well. In cluster 3, sites J9 and J8 had similar features compared with site J10 during the summer season. However, during the winter season, the site J7 and J6 has similar characteristics as compared with sites J9 and J8. The sites J7, J6, J9, and J8 had similar characteristics as compared with J10.

The water quality differences in three clusters during summer and winter seasons clearly reflected the difference in basin origins, morphology, and especially the influence of anthropogenic pollution. During the summer season, cluster 1 is controlled by the similar natural backgrounds and the similar sources of pollutants. The sources of pollutant are mainly geogenic, e.g., higher concentration of Ca, alkalinity, and EC. During the winter season, the similar nature is observed for cluster 1. However, the improved water quality at station J5 during the winter season revealed either the assimilating capacity or self-purification of the river in this area (Kannel et al. 2008). This site is also fed by major tributaries Vishav and Rambiar that may be responsible for the high water quality at this site. Cluster 2 during the summer season is affected by both the sewage and agricultural influents, whereas cluster 3 is mainly influenced by the sewage and other wastes. During the winter season, the influence of agricultural activities on cluster 2 is reduced, because during this season, no agricultural activities are carried out. During the winter season, the combination of J6 and J7 sites with cluster 3 reflects the control of sewage. Moreover, cluster 1 represented mostly upstream sites and indicated better physical as well as chemical water quality than cluster 2 and cluster 3. The worsening of the water quality in downstream stations J5, J7, and J8 reflected severe pollution due to the pollutions from either the domestic wastewater and/or agricultural runoff supplemented with limited pollution from certain industrial effluents. Thus, the results indicated the presence of three different water qualities in the catchment area. Further, from the analysis, it is also implied that for the rapid spatio-temporal assessment of water quality of the upper part of the Jhelum river, only one sampling station in each cluster may serve as a good station than the whole site network (Li et al. 2014; Xu et al. 2014; Dobsa et al. 2014). Additionally, the employed CA technique was found to be useful enough in the classification of river water into certain groups. The categorization of the sampling stations may further reduce the need for abundant sampling stations. Thus, the advantage of this technique is that future sampling programs can be properly planned and only one site will be sampled among sampling sites which fall into the same cluster and thereby will be cost effective.

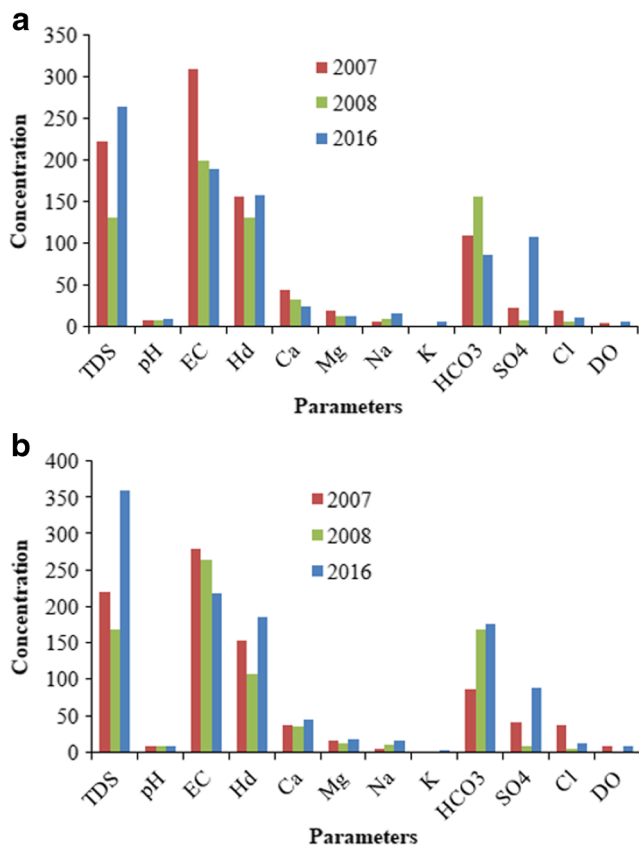


## Comparison with other previous studies

There are a number of studies on the water quality of the river Jhelum (e.g., Sunder 1983; Mir et al. 2016; Rather et al. 2016; Mehmood et al. 2017). The comparison of the present results with Mehmood et al. 2017 indicated that overall, the TDS, pH, Hd, Na, K, SO<sub>4</sub>, and DO observed during the summer season have increased from 2007 to 2016 (Fig. 7). However, during the winter season, the results indicated an increase in Ca, Mg, and HCO<sub>3</sub> in addition to the ions of the summer season thereby indicating a direct impact of the anthropogenic sources on the water quality parameters. But, there are certain parameters that do not follow a similar increasing trend which is probably due to the variation in interannual/monthly sampling time periods. For instance, in the present study, the sampling has been carried out in August, whereas in Mehmood et al. (2017), the sampling period was the month of June 2014–2015. Moreover, in comparison to Mir et al. (2016), most of the parameters indicated a similarity in concentration during both the seasons with small inter-seasonal/ or monthly variations attributed to the variation in the time of sampling periods. For instance, Mir et al. (2016) have carried out the sampling in July and January 2008–2009, whereas in the present study, the

sampling has been carried out in August and February 2007. In general, the Kashmir or Jhelum river basin witnesses a significant variation in the atmospheric temperature from January to December or summer season to autumn season of the year. These variations highly impact the melting of the snow/glaciers which are main contributors of runoff to the streams/ rivers and groundwater discharge, the agricultural/ horticultural activities in the area, and other allied sectors such as tourism. Thus, the variations in the river water quality gives a direct link between these factors and behaves accordingly.

In this study, an increase in the total dissolved solids has been observed from 1983 to 2007. For example, Sunder, 1983 has reported the TDS of the Jhelum River of 118 mg/l and EC of 196  $\mu\text{S cm}^{-1}$  which is lower as compared with the present study concentration of 222.8 and 310 of TDS and EC respectively for which the sampling has been carried out in 2007. To further understand this trend, the present study results in comparison to the Mehmood et al. (2017) showed a continuous increase in the concentration of TDS and EC. For example, Mehmood et al., 2017 has reported a TDS and EC of 264.1 and 189.5 respectively. Almost similar results have been reported by Rather et al. (2016). Rather et al. (2016) revealed an increase in the concentration of nitrate nitrogen from 185 to 672  $\mu\text{g L}^{-1}$  (260%) over the years. Similarly, the TDS and EC values during the same period have indicated an increase from 118 to 157 (33%) and 196 to 239  $\mu\text{S cm}^{-1}$  (22%). Overall, these results suggested a direct human footprint which is probably due to the expansion in municipal and settlement, increase in population, and excessive use of fertilizers and pesticides in agricultural fields in the Kashmir/Jhelum basin (Amin et al. 2014; Rather et al. 2016). Similarly, the increase in TDS and EC are considered the direct impacts of the forest degradation and deforestation in the basin which may have probably increased the sediment load in the Jhelum river (Romshoo and Muslim 2011; Romshoo and Rashid 2014a, b). Moreover, a warmer climate can also enhance the pollution load of nutrients to the river through the changes in precipitation and resulting discharge patterns, affecting the concentration of ions and nutrients (Mir et al. 2016).



**Fig. 7** Comparison of the major ions of the present study with the Mir et al. (2016) and Mehmood et al. (2017) for two seasons **a** summer season and **b** winter season at the Jhelum River

## Conclusions

In this study, multivariate statistical techniques for the assessment of spatio-temporal variation of river water quality, identification of pollution sources/factors, and identification of significant controlling parameters and subsequent classification of the sampling stations/sites in terms of different water quality levels have been employed. The technique of PCA/FA has been successfully employed to take out the parameters that are most important in the assessment of seasonal variations of water quality of the Jhelum River. The PCA/FA indicated that in the summer season, 95.7% of the total variance is described

by six factors while 85.8% of the total variance in the winter season is explained by four factors that are attributed to natural pollution, agricultural runoff, and domestic and municipal wastewater sources. Additionally, the technique of CA grouped the sampling stations/sites into three statistically significant groups which showed a significant variation between the two studied seasons as per the similarity in the pollution load. Based on the observations and gained information, it is desirable to design optimal sampling strategies for this area that can be used for the reduction of the number of sampling stations and connected cost.

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