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Water Quality Assessment of River Soan (Pakistan) and Source Apportionment of Pollution Sources Through Receptor Modeling

Summya Nazeer[1] · Zeshan Ali[2] · Riffat Naseem Malik[3]

Abstract The present study was designed to determine the spatiotemporal patterns in water quality of River Soan using multivariate statistics. A total of 26 sites were surveyed along River Soan and its associated tributaries during pre- and post-monsoon seasons in 2008. Hierarchical agglomerative cluster analysis (HACA) classified sampling sites into three groups according to their degree of pollution, which ranged from least to high degradation of water quality. Discriminant function analysis (DFA) revealed that alkalinity, orthophosphates, nitrates, ammonia, salinity, and Cd were variables that significantly discriminate among three groups identified by HACA. Temporal trends as identified through DFA revealed that COD, DO, pH, Cu, Cd, and Cr could be attributed for major seasonal variations in water quality. PCA/FA identified six factors as potential sources of pollution of River Soan. Absolute principal component scores using multiple regression method (APCS–MLR) further explained the percent contribution from each source. Heavy metals were largely added through industrial activities (28 %) and sewage waste (28 %), nutrients through agriculture runoff (35 %) and sewage waste (28 %), organic pollution through sewage waste (27 %) and urban runoff (17 %) and macroelements through urban runoff (39 %), and mineralization and sewage waste (30 %). The present study showed that anthropogenic activities are the major source of variations in River Soan. In order to address the water quality issues, implementation of effective waste management measures are needed.

Rivers are crucial freshwater resources due to their wide applications in domestic, industrial, agriculture, and recreational activities (Razamkhah et al. 2010; Mustapha et al. 2012). The water quality of a river is influenced by multiple factors ranging from catchment's lithology, topography, and climate, atmospheric deposition to several anthropogenic factors (Shrestha and Kazama 2007; Iqbal and Shah 2014). The domestic sewage and industrial effluents represent a regular anthropogenic source of pollution, which contributes largely through the point sources. On the other hand, surface run-off, which is mainly a season-dependent phenomenon, represents a diffuse source of pollution that carries various pollutants not only from urban areas but a major portion also is contributed from agriculture fields (Singh et al. 2004). The diffuse or non-point sources of pollution are difficult to manage due to their complicated mode of mobility in river catchment and influx in rivers through wide surface area (Kotti et al. 2005). Rivers flanked by urban areas are more susceptible to pollution, especially in developing countries where the natural waterways are the ultimate sinks for urban wastewater (Singh et al. 2004; Jadoon et al. 2012). Downstream sections of rivers are particularly at greater risk of degradation due to collective impact of pollution influx from upstream sections (Chang 2008).

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It is estimated that 40×10^9 m^3/year of wastewater is generated by Rawalpindi, which is either used for irrigation of crops or discharge in River Soan. Approximately 1000 tons of garbage and construction material is disposed daily in Nullah Lei. The bed of Soan River also is used as a garbage station for disposal of solid waste on a temporary basis. Islamabad is the capital and the most organized city of Pakistan, but industrial effluents are discharged from its two industrial zones directly or indirectly into the Soan River, because it lacks an appropriate system for treatment of industrial effluents (Azizullah et al. 2011). Only a few industrial units have acquired antipollution equipment, but those are not functioning properly due to lack of maintenance. These units release slags, gases, and untreated effluents that fall directly or indirectly in River Soan. One ton of particulate matter is emitted daily from the steel furnaces. A survey conducted by the Environmental Protection Agency has reported that DO as low as 0.9 mg/L, BOD as 63.5 mg/L, COD as 162.5 mg/L, whereas Pb and Cd concentrations were found exceeding NEQ's (Pb: 0.5 mg/L and Cd: 0.1 mg/L) in streams passing through an industrial area. It has been reported earlier that effluents released from the Industrial area of Humak model town has contaminated River Soan with Ni, Cr, Cd, and Pb (Mian et al. 1998). Jalil and Khan (2012) analyzed the physicochemical and bacteriological conditions of Soan River and reported that the Soan River and specifically the Kaurang River has become unfit for human consumption and existence of aquatic life.

To sustain imperative role of rivers in both aquatic and terrestrial ecosystems, it is inevitable to restore and conserve these resources through their effective management, which primarily rely on assortment of consistent data on their water quality (Mustapha and Abdu 2012; Wang et al. 2013; Nazeer et al. 2014). Assessment of water quality on the basis of water-quality index (WQI) was recently reported for River Soan, which drained one of the most urbanized catchment of Pakistan (Nazeer et al. 2014). Although variations in water quality could be predicted considering WQI, the pollution sources could not be well described on the basis of WQI (Wunderlin et al. 2001). Hence, a multivariate approach was needed to evaluate the water quality of Soan River. The present study was designed to evaluate the influence of anthropogenic and natural processes on water quality and the apportionment of different sources for their contribution in affecting water quality. Furthermore, it is attempted to determine the similarities in sampling sites on the basis of water quality and to sort out those variables that best described spatiotemporal trends in data. The findings will be useful for the water-quality manager to design an effective monitoring program for pollution control in River Soan.

Methodology

Study Area

The River Soan is located in northern Pakistan between 71°45′ and 73°35′ east longitude and 32°45′ to 33°55′ north latitude (Fig. 1). The river has its origin in lower Himalayan foothills and drained catchment area of approximately 10,999 km^2. Study area exhibits cold Himalayan climate in northern part while it has severe hot climate in southern region. The climatic condition of the study area is largely categorized as "Subtropical Triple Season Moderate Climate Zone." The region receives average rainfall of 1789 mm in north to 783 mm per year in southwestern part, whereas the major rainfall (>50 %) occurs during monsoon season, which extends from July to September (Hagler 2007). The annual temperature also is highly variable across the study area, ranging from 9 to 17 °C in north to 15 to 35 °C in southwest. Study area exhibits diverse lithological features based mainly on limestone, shale, continental sand stones, and clay belong to eocene, miocene epoch, Pliocene, and lower pleistocene ages (Sheikh et al. 2007). The river receives numerous tributaries on its way to the River Indus, among which the River Kaurang, River Ling, and Nallah Lei are noticeable. The major domestic need for water of more than 3 million populations of Rawalpindi and Islamabad is accomplished through Simly and Rawal Lake reservoirs built on River Soan and its tributary the River Kaurang respectively.

Upstream of River Soan is characterized by distinct topography of lower Himalayan foothills having high elevated (>550 m) hilly terrain with numerous valleys and steep gradient. Forest is the predominant land use at upstream reaches of River Soan. Upstream catchment slopes towards southward to the piedmont fold, which constitute the plain area of the Rawalpindi and Islamabad. Upper and lower zones of eastern section are characterized by rainfed and irrigated agriculture landuses respectively. Western section of midstream exhibit intense urbanization, because two major cities (Rawalpindi and Islamabad) are located here. More than 1200 registered industrial units are working in Rawalpindi and Islamabad, which include pharmaceutical industry, re-rolling mills, flour mills, marble cutting and polishing units, and oil and ghee industries. Downstream zone lies in the southwestern part of the catchment area and Pothar plateau. This region is composed of low elevated hills, plateaus, and undulating plains of Attock and Chakwal districts. Rainfed agriculture and wasted land due to deep gullies and gorges are the main landuse at river downstream.
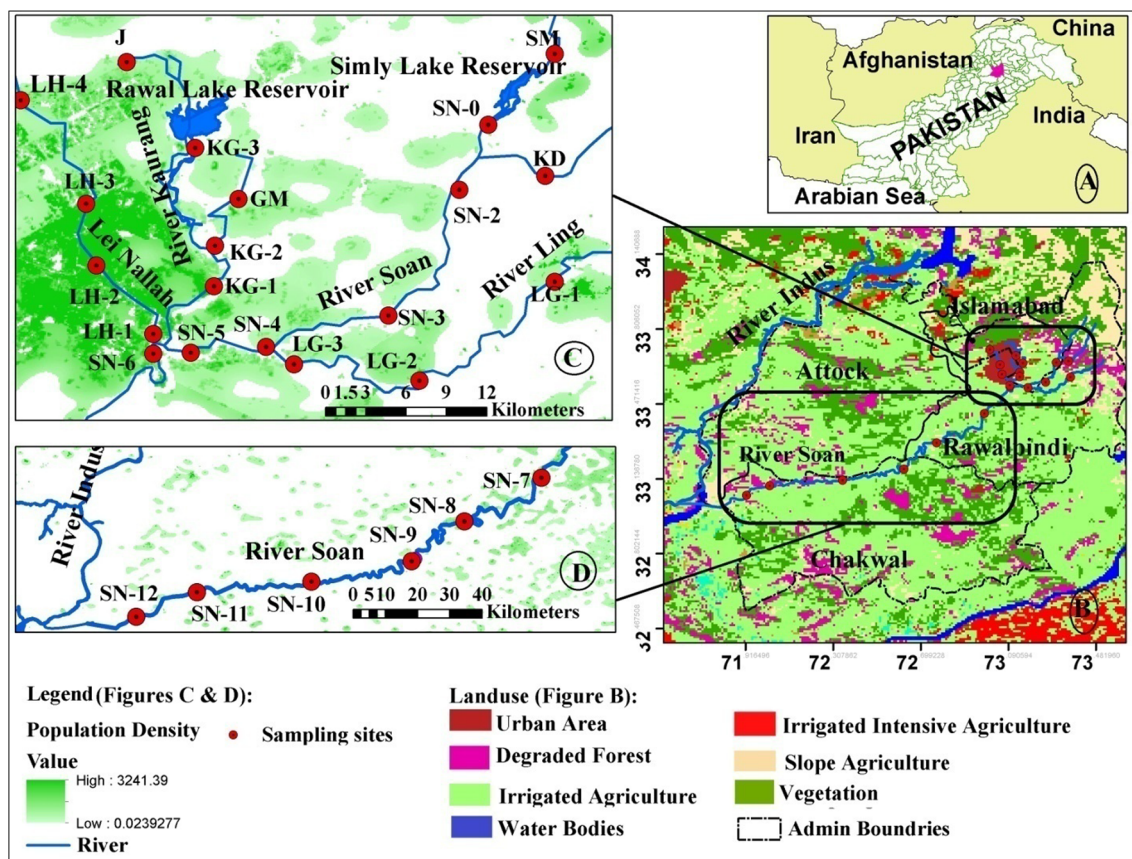
Fig. 1 Map showing landuse patterns and population density in study area and location of sampling sites on River Soan and its tributaries (Color figure online)

Sampling and Physicochemical Analysis

Water samples were collected from 26 sampling located on the River and its tributaries during pre-monsoon (April–May) and post-monsoon season (September–October) in 2008 (Fig. 1). The survey conducted during the base flow periods and daylight. Triplicate water samples were collected from 25-cm depth where applicable using the grab method. Different parameters, such as temperature, pH, DO, TDS, specific conductivity, and salinity, were recorded in the field using portable Hydrolab Surveyor (MS 5 Surveyor Hach Environmental) and turbidity was measured with 2100P turbiditimeter (HACH). Water samples were transported in 2-L polythene plastic bottles first cleaned with metal-free soap and then rinsed with distilled water and finally kept in 10 % HNO_3 overnight. All samples were transported in ice boxes conserved at 4 °C and delivered to the laboratory on the same day. All samples were kept at 4 °C until further lab analysis.

Water samples were analyzed for different parameters in laboratory. Analyses conducted in lab included Alkalinity (Acid–Base titrometry), chlorides (Silver-nitrate titrometry), COD kits (HACH kits based spectrometric Methodology), orthophosphates (ammonium molybdate method), nitrate-

nitrogen (phenol disulphonic method), ammonia–nitrogen (phenate method), and sulphates (barium chloride method) as described previously (APHA 1998). Water samples were filtered through Whatman filter paper (pore size = 0.45 μm) for estimation of dissolved metals and acidified with nitric acid to adjust pH <2 to preserve samples (Sadeghi et al. 2012). Water samples were run on fast sequential Atomic absorption spectrometer for analysis of dissolved metals.

Concentration of metals was determined through calibration curve of standard solutions using Atomic Absorption Spectrometry (Variance FSS-240). The detection limits determined for Cd, Cr, Cu, Fe, Pb, Ni, and Zn were 0.009, 0.004, 0.002, 0.005, 0.003, 0.002, 0.003, 0.0007, and 0.009 mg/L, respectively. The blanks for both procedure and reagents were treated and measured in parallel to the samples using the same procedure. Standard reference material SRM-1673e was used to assess the precision (Relative Standard Deviation-RSD) and recovery of running procedure followed for quantification of metals in water. Precision for different metals was detected in the range of 5 % to 10 %, whereas recoveries for all the metals were within range of 92–111 %. Results of quality control measures validate the reliability and repeatability of analytical procedure followed in present study.

Multivariate Analysis

The multivariate statistical techniques have been widely used in various studies for the explanation of spatiotemporal variations and interpretation of chemical/physical characteristics of water-quality parameters (Simeonov et al. 2000; Wang et al. 2013) compared with univariant techniques, which usually fail to give adequate information on multivariate dataset (Santos-Roman et al. 2003). In the present study, four multivariate techniques, such as HACA, PCA/FA, DFA, and APCS–MLR, were used for the water-quality assessment and interpretation of the results.

In the present study, CA was performed on the normalized dataset using Euclidean similarity matrix as a distance measure and Wards method as a linkage technique. The linkage method was reported as *Dlink/Dmax* where *Dlink* and *Dmax* correspond to the linkage distances for a specific object and maximum distance respectively (Singh et al. 2005a, 2005b). To standardize the linkage distance along y-axis, the *Dlink/Dmax* measure was multiplied by 100 (Wunderlin et al. 2001). Cluster significance was based on the criterion of 0.66 *D*max.

Principal component analysis (PCA) is a widely used ordination technique for unfolding the ecological gradients and to explore spatiotemporal trends in limnological studies (Perona et al. 1999). Data transformation is performed to reduce the set of intercorrelated variables to the set of uncorrelated (orthogonal) variables (Yusuf et al. 2013; Retnam et al. 2013). Factor analysis is designed to reduce the contribution of less significant variables to decrease the complication in data that have passed through PCA (Shrestha and Kazama 2007; Chen et al. 2015). Varimax (variance maximizing) rotation is the most common rotation approach, which is generally applied to reallocate the variance and present the better interpretations of the factors that after varimax rotation are termed as varifactors (VF) (Murillo et al. 2013).

The discriminant function analysis (DFA)—a supervised pattern recognition technique—is used to determine whether prior defined groups vary in terms of a mean of a variable and afterwards DFA find out the group that particular variable is associated (Qadir et al. 2008; Chen et al. 2015). The DFA yielded discrimination functions (DFs) for each group using standard, forward, and backward stepwise modes. In DFA-based spatial analysis of water-quality data, sites were used as grouping variable while temporal analysis used seasons as grouping variables. These grouping variables were taken as dependent variables, while different water-quality attributes were taken as independent variables.

The number and characteristics of possible sources were determined through PCA/FA after which the source contribution to the characteristic pollutant was determined through absolute principal component scores using multiple regression method (APCS–MLR) (Guo et al. 2004; Singh et al. 2005a, 2005b). The quantitative contributions from each source for each variable/pollutant were then compared with measured concentrations.

Results

Temporal Trends in Water Quality

The physicochemical parameters of water quality recorded during pre- and post-monsoon at different sampling sites of River Soan and its associated tributaries are illustrated in Table 1. Seasonal variations determined through Spearman correlation matrix for season-variables showed that among different parameters, COD, ammonia, temperature, pH, Cd, Pb, Ni, Cu, and Cr were significantly correlated with season. Strong correlations were found for Cu ($r = 0.72$) followed by Ni ($r = 0.65$), ammonia ($r = 0.57$), Pb ($r = -0.5$), pH ($r = -0.48$), COD ($r = -0.42$), temperature ($r = -0.4$), Cd ($r = 0.37$), and Cu ($r = 0.34$). Temporal trends were further analyzed through DFA. Raw data divided into pre- and post-monsoon seasons was used for temporal DFA. Discriminant functions of forward stepwise and backward stepwise modes are presented in Table 2. Forward stepwise mode involves the stepwise addition of significant variables until no significant variation is found, whereas backward stepwise mode involves the removal of insignificant variables until no significant variation is found. The standard, forward stepwise, and backward stepwise assigned 96, 92, and 90 % respectively of the cases correctly using 23, 9, and 6 variables respectively. Temporal trends as identified through DFA revealed that COD, DO, pH, Cu, Cd, and Cr could be attributed for major seasonal variations in water quality (Table 2). Box and whisker plots revealed that COD and pH were high during pre-monsoon, whereas DO and concentrations of heavy metals, such as Cu, Cd, and Cr, were high during post-monsoon (Fig. 2).

Spatial Trends in Water Quality

In order to analyze the similarity among different sampling sites along the spatial scale, cluster analysis was conducted which grouped 26 sampling sites into three spatial groups ($(D\mathrm{link}/D\mathrm{max}) \times 100 < 60$) on the basis of water quality (Fig. 3). Cluster 1 included sites SM, SN-0, SN-2, SN-3, SN-4, SN-5, LG-1, LG-2, LG-3, J, LH-4, and KD, which were located in river upstream and suburban midstream. Cluster 2 included downstream sites, such as SN-7, SN-8, SN-10, SN-11, and SN-12, and sites located in close

Table 1 Mean and standard deviation of physicochemical parameters of water quality of River Soan

Sites	Units	Temp (°C)	pH	SpCon (mS/cm)	Sal ppt	Turb NTU	DO mg/L	Alk	Cl⁻	COD	PO_3^{2-}	SO_4^{2-}	NO_3^{2-}	NH_3	Mg	K	Ca	Cd	Zn	Pb	Fe	Ni	Cu	Cr
SM	Mean	22.0	6.8	0.48	0.21	18.9	7.8	112.0	46.2	17.1	0.06	8.6	5.0	0.07	13.9	1.2	47.9	0.00	0.01	0.25	0.09	0.14	0.04	0.04
	S.D	4.2	0.2	0.00	0.01	14.4	3.1	11.3	11.9	18.2	0.02	6.0	0.6	0.10	0.9	0.6	0.9	0.00	0.02	0.04	0.05	0.18	0.04	0.05
SN-0	Mean	24.3	8.4	0.46	0.23	5.7	10.2	111.0	54.2	31.1	0.03	34.7	0.6	0.14	15.8	3.3	56.8	0.00	0.04	0.16	0.00	0.15	0.04	0.04
	S.D	0.1	0.1	0.08	0.01	1.5	1.6	29.7	0.7	43.8	0.03	7.3	0.5	0.09	0.7	3.0	10.4	0.00	0.03	0.01	0.00	0.15	0.04	0.05
KD	Mean	23.4	8.0	0.48	0.22	16.4	8.8	180.0	52.9	51.6	0.05	26.0	3.7	0.10	18.4	14.1	46.6	0.02	0.02	0.29	0.01	0.18	0.03	0.04
	S.D	2.3	0.6	0.13	0.02	15.5	1.1	14.1	15.1	68.5	0.05	17.6	1.6	0.06	0.2	16.6	15.6	0.01	0.03	0.41	0.02	0.20	0.04	0.05
SN-2	Mean	26.2	8.6	0.47	0.20	8.0	10.0	92.5	61.1	14.0	0.03	56.0	3.6	0.05	19.0	1.5	45.0	0.00	0.01	0.49	0.05	0.14	0.05	0.05
	S.D	3.5	0.4	0.16	0.04	4.3	0.1	74.2	9.1	17.0	0.02	40.4	2.0	0.03	1.3	0.1	2.6	0.00	0.00	0.23	0.05	0.20	0.04	0.05
LH-4	Mean	24.5	8.5	0.76	0.35	13.5	8.7	188.0	32.1	5.6	0.01	69.1	3.4	0.09	33.1	1.9	103	0.01	0.02	0.33	0.03	0.30	0.12	0.04
	S.D	0.8	0.5	0.18	0.02	5.8	0.9	45.3	14.4	9.7	0.04	10.5	3.4	0.07	5.9	1.5	4.8	0.01	0.00	0.46	0.05	0.13	0.17	0.01
LG-3	Mean	26.2	9.0	0.63	0.29	63.2	11.3	140.0	66.1	62.0	0.06	26.5	4.1	0.26	17.1	1.7	42.0	0.00	0.00	0.15	0.14	0.27	0.12	0.07
	S.D	1.7	0.6	0.30	0.11	25.3	2.7	127.3	16.2	67.9	0.00	22.0	0.9	0.30	5.0	0.1	10.2	0.00	0.00	0.21	0.20	0.13	0.13	0.03
LG-1	Mean	23.9	9.0	0.56	0.25	4.1	9.3	115.0	45.2	20.9	0.18	18.4	4.7	0.29	17.6	1.8	53.5	0.00	0.03	0.52	0.00	0.27	0.11	0.09
	S.D	0.8	0.7	0.13	0.01	2.1	0.9	134.4	13.4	24.2	0.12	11.9	0.1	0.37	9.1	0.6	1.0	0.00	0.04	0.73	0.00	0.12	0.13	0.02
LG-2	Mean	24.3	9.0	0.57	0.33	7.2	9.4	136.0	34.3	18.3	0.04	38.6	12.2	0.19	17.4	2.2	35.6	0.01	0.05	0.14	0.06	0.29	0.11	0.06
	S.D	1.8	0.7	0.16	0.14	4.2	1.0	79.2	28.8	16.6	0.00	15.6	10.5	0.27	4.4	2.2	8.4	0.01	0.04	0.19	0.08	0.12	0.13	0.01
J	Mean	18.9	8.3	0.48	0.23	5.3	9.1	140.0	43.7	9.5	0.05	81.7	6.6	0.18	12.1	3.1	49.9	0.01	0.02	0.10	0.00	0.14	0.05	0.06
	S.D	3.7	0.4	0.22	0.09	4.5	0.6	28.3	8.4	12.3	0.03	115.5	1.8	0.20	1.6	1.2	1.3	0.01	0.03	0.14	0.00	0.19	0.01	0.03
SN-3	Mean	24.3	8.7	0.49	0.21	17.0	9.7	113.0	50.4	18.3	0.01	11.0	3.2	0.07	18.3	1.2	46.4	0.05	0.02	0.12	0.06	0.19	0.00	0.05
	S.D	4.6	0.8	0.16	0.03	4.7	0.3	60.8	9.5	19.4	0.04	5.4	2.7	0.05	0.2	0.6	6.8	0.07	0.00	0.05	0.08	0.14	0.00	0.04
SN-4	Mean	27.2	8.5	0.55	0.26	89.2	8.3	125.0	63.6	27.5	0.10	28.6	8.3	0.10	17.4	1.5	51.5	0.00	0.01	0.21	0.00	0.16	0.05	0.06
	S.D	0.4	0.3	0.24	0.10	19.6	1.1	21.2	8.4	20.5	0.01	22.3	4.9	0.07	1.1	0.1	3.6	0.00	0.01	0.08	0.01	0.13	0.05	0.03
GM	Mean	28.8	8.7	0.72	0.31	274.8	8.9	175.0	45.8	57.4	0.06	33.8	15.2	0.18	22.1	2.9	73.8	0.01	0.02	0.17	0.08	0.15	0.03	0.03
	S.D	2.6	0.7	0.22	0.02	311.5	0.4	77.8	19.5	77.3	0.07	8.4	15.0	0.20	4.4	1.3	4.4	0.00	0.01	0.23	0.09	0.10	0.02	0.03
KG-3	Mean	26.5	8.2	0.54	0.27	29.1	9.8	243.0	38.8	54.7	0.07	51.6	3.8	0.10	18.3	3.5	74.4	0.00	0.02	0.05	0.15	0.24	0.10	0.04
	S.D	4.9	0.5	0.04	0.01	28.0	0.6	46.7	15.5	75.4	0.06	10.1	3.9	0.10	1.2	0.9	4.7	0.00	0.00	0.06	0.06	0.13	0.13	0.01
SN-5	Mean	24.5	8.3	0.64	0.27	29.2	4.8	133.0	55.7	33.0	0.04	33.1	20.2	0.22	17.4	1.8	49.0	0.00	0.02	0.32	0.21	0.17	0.06	0.05
	S.D	3.7	0.7	0.15	0.01	24.8	2.6	89.1	5.6	35.4	0.04	9.5	21.6	0.06	2.3	1.0	14.7	0.00	0.01	0.11	0.23	0.11	0.06	0.05
KG-1	Mean	27.8	8.3	1.27	0.58	22.0	3.9	340.0	120	144.0	2.10	107	4.3	2.64	34.6	16.9	117	0.01	0.01	0.10	0.22	0.27	0.09	0.06
	S.D	2.9	0.7	0.40	0.09	8.7	0.9	155.6	54.5	67.9	0.20	2.7	0.6	3.74	13.3	2.8	16.7	0.01	0.01	0.01	0.10	0.15	0.11	0.03
KG-2	Mean	26.7	8.2	1.09	0.49	23.8	3.8	359.0	56.7	59.5	2.01	134	3.8	2.96	26.4	11.5	114	0.00	0.02	0.23	0.15	0.24	0.10	0.04
	S.D	1.5	0.4	0.20	0.01	4.6	0.4	41.0	18.3	4.9	0.30	77.1	1.7	4.12	4.3	1.6	10.8	0.00	0.02	0.02	0.10	0.18	0.13	0.01
LH-3	Mean	24.2	8.3	1.13	0.53	45.8	0.6	307.0	68.1	62.5	1.65	28.6	3.0	10.5	24.6	7.9	112	0.01	0.03	0.32	0.11	0.32	0.11	0.05
	S.D	1.1	0.7	0.24	0.04	3.0	0.6	117.4	9.1	2.1	0.68	40.4	2.7	14.9	0.8	1.3	3.3	0.00	0.01	0.45	0.13	0.15	0.16	0.02

Table 1 continued

Sites	Units	Temp (°C)	pH	SpCon (mS/cm)	Sal ppt	Turb NTU	DO mg/L	Alk	Cl⁻	COD	PO₃²⁻	SO₄²⁻	NO₃²⁻	NH₃	Mg	K	Ca	Cd	Zn	Pb	Fe	Ni	Cu	Cr
LH-2	Mean	26.4	7.9	1.30	0.60	86.7	0.5	412.0	92.2	283.5	3.04	77.3	28.3	9.15	34.8	15.7	112	0.00	0.03	0.54	0.08	0.30	0.12	0.03
	S.D	3.2	0.6	0.42	0.09	23.1	0.5	67.9	34.8	102.5	0.23	2.2	39.5	9.65	0.3	1.9	17.1	0.00	0.00	0.57	0.11	0.08	0.15	0.02
LH-1	Mean	25.9	8.3	1.36	0.69	65.6	4.6	450.0	97.2	171.0	3.07	78.4	3.4	10.2	33.6	18.4	114	0.01	0.04	0.44	0.15	0.31	0.11	0.04
	S.D	2.3	0.5	0.09	0.01	4.7	0.2	70.7	27.8	43.8	0.26	2.1	3.5	12.3	4.1	2.1	11.8	0.01	0.03	0.52	0.05	0.14	0.14	0.01
SN-6	Mean	26.0	8.5	0.93	0.43	26.7	7.3	231.0	87.7	50.0	0.64	45.2	4.8	0.15	21.1	7.4	78.4	0.00	0.02	0.14	0.06	0.22	0.06	0.05
	S.D	3.1	0.6	0.11	0.15	4.9	2.2	83.4	6.0	48.1	0.07	30.7	0.1	0.21	3.3	6.1	26.9	0.00	0.01	0.12	0.06	0.19	0.07	0.05
SN-7	Mean	29.4	8.7	1.20	0.58	31.8	17.2	245.0	75.5	74.0	0.98	78.3	6.6	0.05	27.5	10.4	116	0.01	0.02	0.37	0.12	0.21	0.07	0.05
	S.D	1.2	0.7	0.11	0.02	18.0	2.2	7.1	19.7	2.8	0.91	25.4	2.5	0.01	3.7	1.1	28.4	0.01	0.01	0.06	0.17	0.15	0.08	0.04
SN-8	Mean	27.5	8.7	1.16	0.53	29.4	11.3	228.0	91.2	77.5	1.48	81.3	38.2	0.21	28.2	19.5	109	0.00	0.02	0.30	0.04	0.19	0.07	0.05
	S.D	2.8	0.9	0.08	0.08	9.3	4.8	17.0	8.1	57.3	0.23	2.2	47.1	0.24	4.8	13.6	4.2	0.00	0.00	0.25	0.05	0.15	0.08	0.05
SN-9	Mean	31.7	9.3	0.72	0.74	65.8	17.8	335.0	82.0	104.0	0.85	54.9	5.4	0.16	26.6	19.4	81.6	0.01	0.01	0.23	0.05	0.23	0.08	0.06
	S.D	5.1	0.4	0.42	0.25	40.3	8.8	289.9	17.6	56.6	0.10	14.4	0.6	0.19	1.2	14.6	10.5	0.01	0.01	0.11	0.07	0.13	0.09	0.01
SN-10	Mean	33.1	9.3	1.14	0.43	86.1	15.9	181.5	102	144.0	0.38	96.1	12.8	0.85	23.5	15.1	37.9	0.00	0.01	0.39	0.16	0.25	0.09	0.06
	S.D	5.2	0.1	0.65	0.19	20.1	5.1	30.4	38.3	70.7	0.22	23.7	11.2	1.02	9.7	9.4	28.8	0.00	0.01	0.16	0.05	0.14	0.10	0.05
SN-11	Mean	32.0	9.4	0.99	0.43	75.4	18.0	225.0	82.5	120.5	0.33	52.4	15.9	0.91	14.6	11.1	25.2	0.01	0.01	0.21	0.13	0.22	0.09	0.06
	S.D	0.0	0.8	0.44	0.16	23.9	5.6	21.2	20.4	29.0	0.08	22.6	20.9	1.18	0.8	4.9	18.8	0.01	0.02	0.13	0.10	0.17	0.11	0.06
SN-12	Mean	30.8	9.4	0.81	0.41	142.0	15.1	159.0	93.9	80.5	0.29	64.4	3.6	0.79	13.4	12.7	28.6	0.00	0.03	0.34	0.15	0.26	0.09	0.07
	S.D	0.4	0.5	0.24	0.15	21.2	6.9	72.1	42.9	26.2	0.22	13.3	2.1	0.13	6.3	8.2	25.6	0.00	0.02	0.16	0.13	0.16	0.10	0.02

Table 2 Classification functions of spatial and temporal trends in water quality of River Soan (all physicochemical variables were selected by standard stepwise mode hence classification function for standard stepwise mode is not presented here)

Variables	Forward stepwise mode			Backward stepwise mode			Forward stepwise mode		Backward stepwise mode	
	LP coefficient	MP coefficient	HP coefficient	LP coefficient	MP coefficient	HP coefficient	Pre-monsoon coefficient	Post-monsoon coefficient	Pre-monsoon coefficient	Post-monsoon coefficient
Alk	0.453	0.704	0.813	0.204	0.295	0.385	0.035	0.042		
Cl^-				0.418	0.567	0.559				
COD							−0.083	−0.104	−0.050	−0.065
PO_3^{2-}	−20.539	−40.928	−34.458	−21.762	−27.591	−21.447				
NO_3^{2-}	−0.074	−0.263	−0.981	0.284	0.388	0.112	0.108	0.1937		
Temp	15.668	19.729	22.858							
pH							38.435	35.623	37.482	34.263
SpCon	25.812	66.048	24.438							
Sal	−44.653	−86.140	22.227							
DO	−4.587	−6.363	−10.067				−0.158	−0.142	−0.163	−0.146
Turb	−0.030	0.055	0.060							
Mg	−5.839	−9.074	−10.011							
K	1.942	4.743	6.103							
Ca	1.286	1.920	2.014	0.214	0.253	0.221				
Cd							37.721	155.803	44.486	154.336
Pb							−2.888	−7.083		
Cu							11.679	66.051	20.792	79.023
Cr							−136.043	−85.162	−150.932	−107.722
Constant	−182.280	−319.408	−420.683	−30.644	−57.952	−85.95	−157.826	−143.031	−151.488	−132.504
Class accuracy	100.00	100.00	100.00	100.00	87.5	100.00	92.3	92.3	88.5	92.3
Total accuracy	100.00			96.15			92.3		90.4	

LP least polluted sites; *MP* moderately polluted sites; *HP* highly polluted sites

proximity to urban areas, such as GM, KG-3, and SN-6. Cluster 3 was comprised of sites LH-1, LH-2, LH-3, KG-1, KG-2, and SN-9, which are located either in urban or close proximity to urban area except SN-9, which is located in river downstream. Spatial variations in the data were interpreted through DFA. Analysis was conducted on raw data set comprising of three clusters formed by cluster analysis. Discriminant functions of forward stepwise and backward stepwise modes are given in Table 2. Standard and forward stepwise mode DFs based on 23 and 12 variables assigned 100 % cases correctly while backward stepwise mode based on six variables assigned 96 % of cases correctly. Backward stepwise mode sorted total alkalinity, orthophosphates, nitrates, Cl^-, and Ca as those variables which significantly discriminate among three groups (Table 2). Box and Whisker plots revealed that orthophosphates, Cl^-, alkalinity, and Ca were higher in cluster 3, which included highly polluted sites of urban midstream, followed by moderately polluted sites of

cluster-2 and least polluted sites of cluster-1 (Fig. 2). Nitrates were higher at moderately degraded sites of cluster-2 followed by cluster-3 and cluster-1 (Fig. 2).

Source Identification of Different Pollutants

To identify the potential source of pollution in river Soan, PCA/FA was applied to normalized data (Table 3). Total of six factors having eigen value >1 were sorted which explained 81 % of the variations in the dataset. Factor 1 explains 40 % of total variations in the data set and showed high loadings of total alkalinity, orthophosphates, specific conductivity, salinity, Ca, Mg, and K. Factor 2 accounted for 16 % of total variations and showed high loadings of temperature, pH, and DO. Factor 3 explained 8 % of total variations in data and showed high loadings of Fe and Cu and moderate loadings of COD, Cd, ammonia, orthophosphates, and Ni. Factor 4 explained 6 % of total variations in data and had high loadings of nitrates. Factors 5 and 6
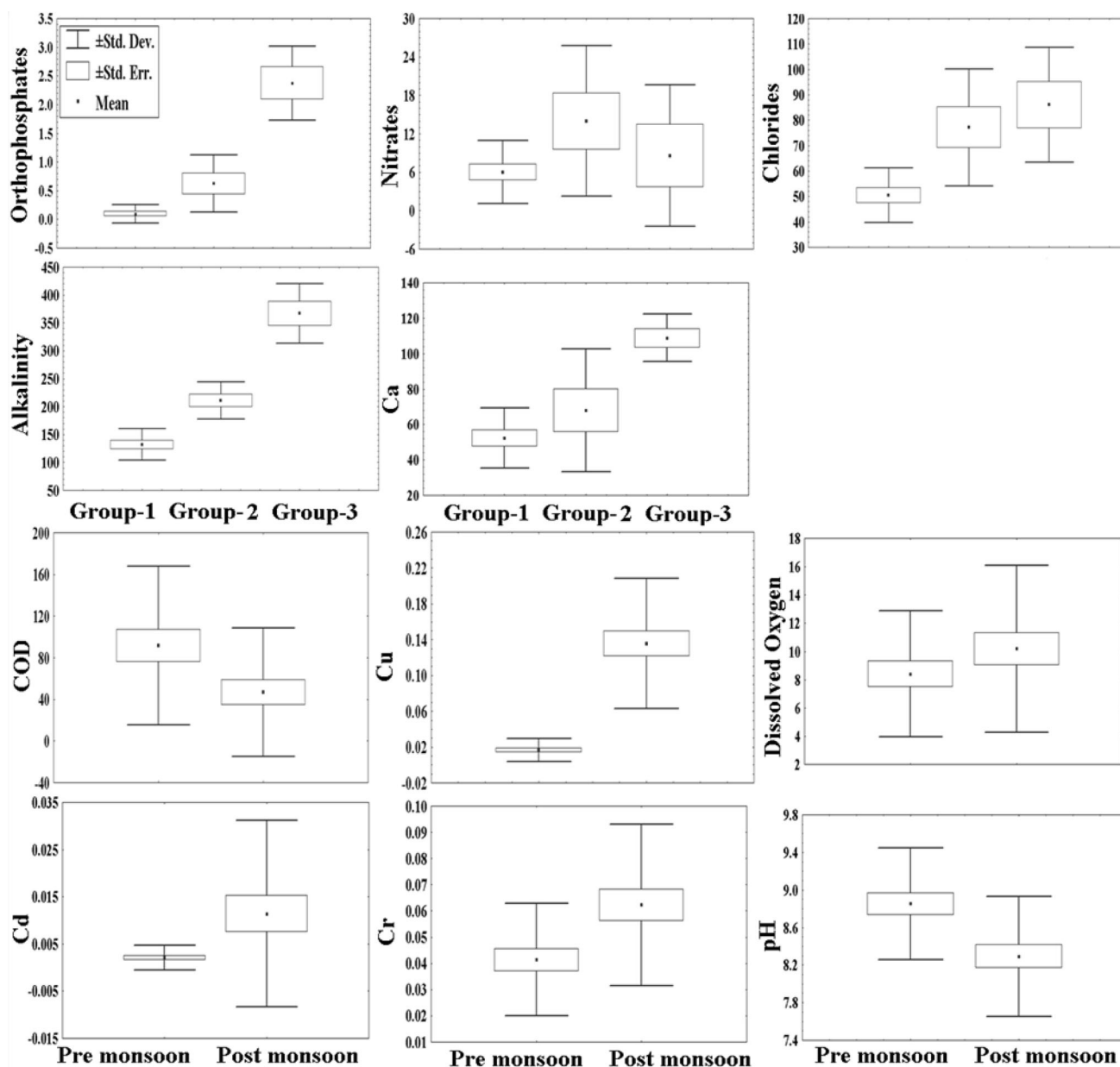
Fig. 2 *Box* and *whisker plots* illustrating the spatial (orthophosphates, nitrates, chlorides, alkalinity, and Ca) and temporal (COD, Cu, dissolved oxygen, Cd, Cr, and pH) trends of water quality of River Soan

explained 5.6 % and 5.3 % of variation in data, respectively, and showed high loadings of turbidity and Zn respectively. To verify the PCA interpretations, factor scores of different groups of sampling sites (identified through cluster analysis on the basis of water quality) were examined so that source contributions could be confirmed through factor scores (Fig. 4). Source profile of factor 1 also showed high scores at highly polluted sites which are located in urban areas (Cluster-3) (Fig. 4). Factor 2 showed high scores of moderately polluted sites (Cluster-2) located in the river

downstream, which suffer from hyper eutrophic conditions (Nazeer et al. 2014) (Fig. 4). Source profile of factors 3 showed high scores of urban midstream (Cluster-3) (Fig. 4). Factor 4 represents the impact of agriculture activities on water quality and showed the high scores of sub urban part of midstream and downstream sites, which have agriculture as main catchment land use (Fig. 4). High scores for factor 5 were noted mainly at suburban midstream sites included in cluster-2 (Fig. 4). Factor scores for factor 6 were measured less than 0 at each cluster (Fig. 4).

Fig. 3 Dendrogram showing the grouping of sampling sites into three clusters on the basis of water quality of River Soan
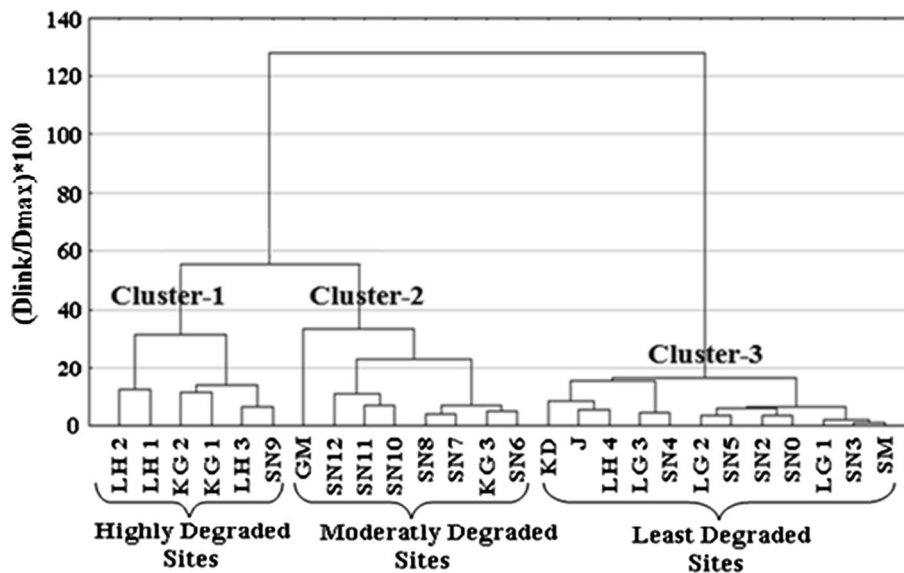
Source Apportionment

The APCS–MLR technique was utilized to determine the contribution of different sources in affecting water quality and the results are presented in Table 4. Predicted concentrations of different parameters hold good accuracy with measured concentrations, which also is confirmed by regression coefficients and the ratio between predicted and measured values. The values of the correlation coefficient (R^2) are the measure of the variance of the observed concentration which could be attributed to the variance of predicted concentration. Organic pollution was mainly added by factor 1 (mineralization and sewage waste), which contributes 27 % followed by factor 3 (urban runoff), 4 (agriculture activities), and 5 (livestock interruptions and bank erosion), which contributes 17, 16, and 14 %, respectively (Fig. 5a). Factor 1 (mineralization and sewage waste) and 6 (industrial activities) accounts for 28 % contribution for heavy metal pollution in water, followed by factor 3 (urban runoff) and 4 (agriculture activities), which contribute 15 and 13 %, respectively (Fig. 5b). Nutrients were mainly added by factor 4 (agriculture activities), which contributes 35 %, followed by factor 1 (mineralization and sewage waste), 5 (livestock interruptions and bank erosion), and 3 (urban runoff), which contribute 28, 17, and 10 %, respectively (Fig. 5c). Factor 3 (urban runoff) contributes 39 % to macro elements, followed by factor 1 (mineralization and sewage waste) and 2 (ecological response factor and natural processes), which contribute 30 and 17 % respectively (Fig. 5d).

Different physicochemical factors, such as DO, turbidity, and specific conductivity, showed characteristic pattern according to their association with catchment land uses (Table 4). DO was mainly affected by elevated growth of

phytoplankton (factor 2: 63.41 %), whereas some unidentified sources (36.58 %) also were controlling DO in river. These sources might be related to hydrological factors like water flow which affects DO in river. Turbidity was mainly affected by livestock interruptions and bank erosion (factor 5: 75.92 %), whereas phytoplankton (factor 2: 24.07 %) also played their role in making water turbid. Specific conductivity was mainly attributed to sewage waste along with natural processes (factor 1: 59.5 %); however, surface runoff from agriculture fields (factor 4: 19.6 %) and urban areas (factor 3: 20.89 %) also raised the specific conductivity of water.

Discussion

Temporal analysis of water quality revealed that COD, DO, pH, Cu, Cd, and Cr could be attributed to major seasonal changes in water quality, which suggests that anthropogenic activities are major sources of seasonal variations in water quality. The impact of anthropogenic activities might be due to the monsoon precipitation which facilitates the soil erosion and accelerates the influx of organic waste and agrochemical runoff from catchment through flooding. Chen et al. (2013) has reported that pollution was considerably high in Jinjiang River, China during the period of high flow while pollution was low to moderate during low-flow period. In Soan Basin, increase in chemical oxygen demand during pre-monsoon was due to sewage waste, which on degradation enhanced the chemical oxygen demand and thus lowered the concentration of dissolved oxygen in water. However, increase in water discharge from reservoirs during monsoon improves flow in the river and enhanced the dissolution of oxygen in water in

Table 3 Factor loadings of different water physico-chemical variables on significant varimax factors (strong loadings are italicized and bold)

Parameters	VF 1	VF 2	VF 3	VF 4	VF 5	VF 6
Alk	*0.883*	−0.067	0.302	0.019	0.16	0.11
Cl⁻	0.613	0.405	0.185	0.431	0.048	−0.091
COD	0.64	0.103	0.411	0.392	0.328	0.029
PO_3^{2-}	*0.866*	−0.22	0.301	0.237	0.045	0.105
SO_4^{2-}	*0.77*	0.207	−0.081	0.007	−0.107	−0.082
NO_3^{2-}	0.185	−0.056	−0.095	0.645	0.314	−0.165
NH_3	0.549	−0.366	0.569	0.117	0.153	0.233
Temp	0.306	*0.818*	0.042	0.222	0.249	0.063
pH	0.052	*0.89*	0.057	−0.078	0.173	−0.069
SpCon	*0.838*	0.143	0.294	0.276	0.064	0.074
Sal	*0.838*	0.265	0.26	0.169	0.078	0.126
DO	−0.274	*0.847*	−0.215	0.093	−0.045	0.009
Turb	0.001	0.27	0.034	0.089	*0.852*	0.112
Mg	*0.845*	−0.213	0.146	0.024	−0.126	−0.116
K	*0.895*	0.067	0.19	0.198	0.076	0.092
Ca	0.433	0.35	0.048	0.095	0.319	−0.293
Cd	0.017	−0.119	−0.449	−0.512	−0.015	0.559
Zn	0.124	−0.046	0.004	0.016	0.082	*0.9*
Pb	0.171	0.169	0.231	*0.659*	−0.289	0.159
Fe	0.158	−0.022	*0.728*	0.199	−0.02	−0.438
Ni	0.386	0.143	0.654	−0.059	−0.325	0.288
Cu	0.361	−0.052	*0.728*	−0.293	0.171	0.016
Cr	−0.616	0.516	−0.051	0.367	−0.236	−0.177
Eigen values	9.486	3.739	1.923	1.281	1.188	1.087
% of Variance	41.242	16.258	8.361	5.568	5.165	4.726
Cumulative % of variance	41.242	57.5	65.861	71.43	76.595	81.321

monsoon and post-monsoon seasons (Chang 2008). Chen et al. (2015) have reported similar findings that increase in flow during the wet season, lowering the COD in Danjiangkou Reservoir Basin in Central China. During post-monsoon, pH was relatively low and concentrations of heavy metals, such as Cu, Cd, and Cr, were high. Monsoon precipitation mobilizes various contaminants from terrestrial ecosystem to aquatic ecosystem by accelerating surface runoff, which brings waste from dumping sites for domestic solid waste, industrial waste, and poultry farms (Nazeer et al. 2014). Diffuse sources of pollution actively play their role during high flows through surface runoff (Kotti et al. 2005). Chang (2008) has reported that the influx of solutes in river increases through surface run off during intense monsoon precipitation. Low pH noted during post-monsoon might be due to the influx of surface runoff, which adds organic waste from solid waste dumping sites as well as agrochemical wastes in river and increases the cationic concentrations in water. Moreover atmospheric depositions also play an additive role in enhancing metal concentration particularly during post-monsoon.

Major spatial variations in water quality were attributed to total alkalinity, orthophosphates, nitrates, Cl⁻, and Ca, which were mainly high at sites grouped in cluster-3 with the exception of nitrates, which was high in cluster-2. Cluster-1 was comprised of the sites located in urban part of river midstream which were characterized by dense urbanization in their catchment and presence of several point sources of pollution in the form of drainage pipes. The sewage and industrial wastes of twin cities of Rawalpindi and Islamabad are directly drained through these pipes into the freshwater streams and rivers mainly in untreated form. In urbanized catchments, municipal and industrial wastes are the major pollutants of aquatic ecosystem (Li et al. 2011). Deliberate release of sewage and industrial wastes through point and diffuse sources at sites of cluster-1 has resulted in increase in organic load in river. Biochemical degradation of organic compounds increases concentration of carbonates and bicarbonates which elevates water alkalinity (Khan et al. 2014). Sewage waste and carbonate geology of the study area could be account for relatively high alkalinity at sites of cluster-3 (Jalil and Khan 2012). High Ca at sites of cluster-3 is

Fig. 4 Factor scores of different groups of sampling sites (identified through cluster analysis on the basis of water quality)
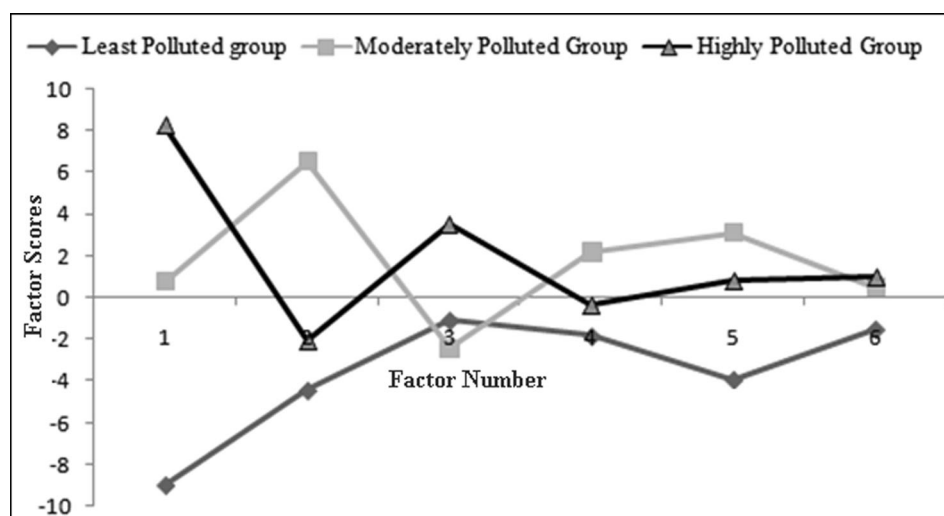
attributed to the local geology as the sites clustered in group are located on Lei Nallah, which drains the Margalla hills rich in limestone (Munir et al. 2011). High alkalinity at these sites could be partly attributed to the weathering of the parent rock material of Margalla hills, which adds bicarbonate ions to the surface water. It is to be noted that some of the sites located at Lei Nallah exhibit DO as low as 0.5 mg/L, but pH did not decrease accordingly as normally occurs. The stability in pH also could be attributed to the weathering of calcareous rocks present in this region. Domestic use of detergents and soaps makes sewage waste an important source of orthophosphates in streams and rivers (Perona et al. 1999). In Soan drainage, sewage pollution is the major source of chlorides and orthophosphates in surface water. Chloride is regarded as a conservative chemical species and serves as an indicator for sewage pollution (Varol et al. 2012; Kumar et al. 2015). Beside sewage pollution, natural sources, urban runoff, and industrial effluents also add chloride to the surface water (Oketola et al. 2013).

Downstream sites were grouped in cluster-2. Nitrates were high in cluster-2, which might be attributed to the agricultural activities which is the major land use at these sites. The organic waste entered in river from midstream region causes major environmental hazard for the aquatic environment at downstream. The downstream sites showed extreme growth of phytoplankton due to influx of nutrients in river mainly from urban midstream. In previous study, hyper eutrophic conditions were reported in downstream region of River Soan in response to the enrichment of river with high nutrient loadings (Nazeer et al. 2014). Some of the sites located in moderately polluted suburban part of river midstream also were grouped in cluster-2. The clustering of downstream sites with moderately impacted sites of suburban midstream showed that due to self-purification

and assimilative capacity of the river, water quality was improved from highly degraded condition (river urban midstream) to a moderate one (Kannel et al. 2007). Upstream and some of the suburban midstream sites were grouped in cluster-3. It was earlier reported that water quality of River Soan at these sites could be classified into good-fair quality classes, whereas none of these site had poor or very poor quality of water (Nazeer et al. 2014). Least deteriorated quality of water at these sites is attributed to relatively less urbanization in the catchment of these sites. Since the pollution increases downstream the gradient as the river passes through different land uses, the upstream reaches often are less polluted than downstream reaches (Kotti et al. 2005; Wang et al. 2015). Poultry farming, tourism, grazing, and deforestation are major environmental threats at river upstream.

The grouping pattern revealed through CA was consistent with classification of river done earlier on the basis of WQI (Nazeer et al. 2014). The results indicate that the CA technique is useful in offering reliable classification of surface waters in the whole region and will make it possible to design a future spatial sampling strategy in an optimal manner, which can reduce the number of sampling stations and associated costs (Shrestha and Kazama 2007).

The sources of pollution in riverine ecosystems can be determined through factor scores estimated through factor analysis (Bu et al. 2010). The high scores correspond to high influence of the factor on the sampling sites (Kannel et al. 2007). Source profile of different factors helps in identification of polluted areas in river catchment which could be useful in assessment of water quality at watershed level (Yan et al. 2015). High loadings of alkalinity, Mg and Ca on first factor point out towards the natural phenomenon of mineralization. Munir et al. (2011) has reported that Ca
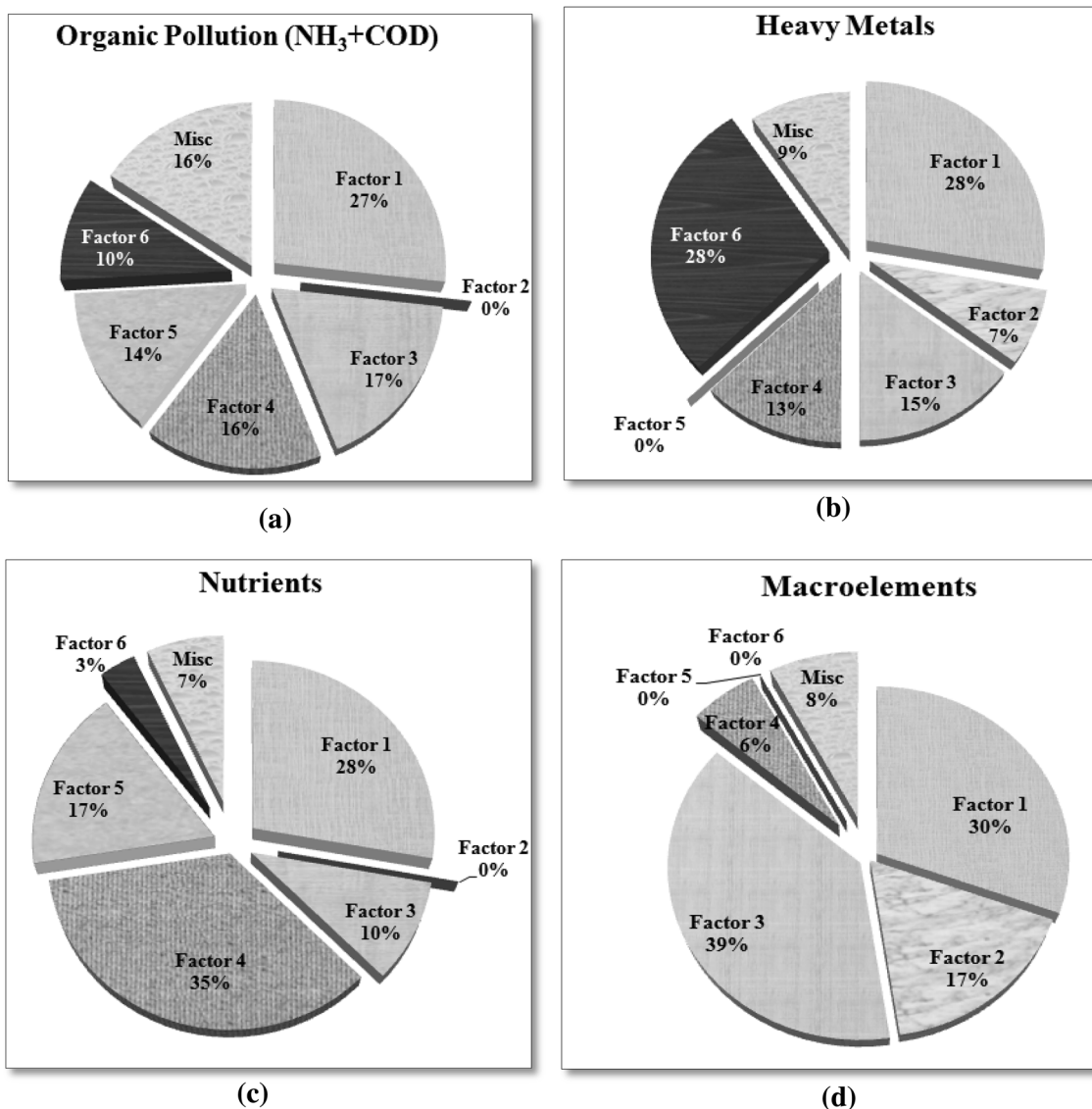
Fig. 5 Source apportionment for different water quality parameters **a** organic pollution (COD + Ammonia), **b** heavy metals (Pb, Cu, Cr, Ni, Zn, Fe, and Cd), **c** nutrients (orthophosphates and nitrates) and macroelements (Mg, Ca, and K). (*Factor 1* sewage waste and mineralization. *Factor 2* ecological response factor and natural variability. *Factor 3* urban runoff. *Factor 4* agriculture activities. *Factor 5* livestock interruptions, bank erosion, and soil erosion. *Factor 6* industrial activities)

and Mg in surface water of this region are mainly contributed by natural sources. Present study revealed the concentrations of Mg and Ca in 1:2, which is consistent with the findings reported for other regions round the globe (Ndungu et al. 2014). Conversely, high loadings of orthophosphates and moderate loadings of COD and ammonia indicate the role of anthropogenic activities, which magnifies the natural processes in altering the water quality. These findings suggest that first factor could be termed as mineralization and sewage pollution factor. Source profile of factors-1 also showed the high scores at highly polluted sites located in urban areas (cluster-3) and drain the domestic sewage and industrial effluents from

urban areas of Rawalpindi and Islamabad (Fig. 5). Addition of sewage waste from the twin cities results in increase in orthophosphates and organic contents. Degradation of organic compounds enhances the ammonia concentration as well as biochemical oxygen demand (Shrestha and Kazama 2007). COD is considered as an indicator of organic pollution which occurs primarily due to degradation of organic waste of sewage and industrial discharges (Ullah et al. 2013; Chen et al. 2015). The dissolved oxygen thus decreases in response to increase in biochemical oxygen demand, which is evident from negative loading of dissolved oxygen on the first factor. Various ions, such as carbonates, bicarbonates, sulfates, phosphates, Na, K, and

Table 4 Source contribution to the different water quality parameters

Parameters	Types of sources							Observed value	Predicted value	Ratio (O/P)	R^2
	S-1	S-2	S-3	S-4	S-5	S-6	S-M				
Alk	100	–	–	–	–	–	–	210.62	210.45	1.0007	0.88
Cl^-	42.29	27.95	–	29.74	–	–	–	66.91	66.884	1.0005	0.726
COD	36.11	–	23.21	22.12	18.54	–	–	68.91	69.011	0.9985	0.86
PO_4^{3-}	53.32	–	18.54	14.6	–	6.44	13.5	0.68	0.667	1.0158	0.957
SO_4^{2-}	100	–	–	–	–	–	–	54.50	54.25	1.0046	0.68
NO_3^{2-}	–	–	–	67.25	32.74	–	–	8.65	8.62	1.0033	0.46
NH_3	31.94	–	33.14	–	–	13.58	21.3	1.57	1.53	1.023	0.813
Temp	19.17	51.28	–	13.93	15.6			26.40	26.38	1.0006	0.77
pH	–	100	–	–	–	–	–	8.47	8.41	1.007	0.62
SpCon	59.5	–	20.89	19.6	–	–	–	0.80	0.79	1.0174	0.86
Sal	54.7	17.29	16.96	11.01	–	–	–	0.38	0.34	1.1295	0.85
DO	–	63.41	–	–	–	–	36.58	9.31	9.4	0.99	0.819
Turb	–	24.07	–	–	75.92	–	–	49.32	50.1	0.984	0.73
Mg	79.83	–	–	–	–	–	20.16	12.10	11.9	1.016	0.68
K	69.78	–	14.8	15.41	–	–	–	3.06	2.99	1.022	0.85
Ca	55.2	44.71	–	–	–	–	–	77.28	77.71	0.994	0.59
Cd	–	–	20.5	35.6	–	35.3	–	36.44	36.78	0.99	0.74
Zn	–	–	–	–	–	100	–	0.01	0.0135	1.047	0.74
Pb	–	–	–	46.52	–	–	54.47	0.08	0.07	1.13	0.84
Fe	–	–	100	–	–	–	–	0.24	0.23	1.031	0.53
Ni	23.34	–	39.57	–	–	17.53	19.64	0.18	0.178	1.006	0.8
Cu	26.11	–	52.67	–	–	–	21.21	0.14	0.148	0.948	0.67
Cr	–	26.98	–	19.2	–	–	53.8	0.04	0.03	1.335	0.826

Cl^-, are added to aquatic ecosystem mainly through sewage waste. These ions and decomposed organic matter increase the dissolved solids and conductivity of water (Yousafzai et al. 2013). The presence of shales, industrial effluents, and oxidation of sulfite ores are the common sources of sulfate in surface water (Chen et al. 2013). In River Soan, leaching of gypsum, domestic use of detergents, and geology of the area has been identified as major sources of sulfates (Jalil and Khan 2012; Mehmood et al. 2013). Calcareous rocks and marble processing units in the urban midstream are greatly attributed for high mineral contents of River Soan. Effluent discharge from manufacturing and processing units could be an important source of K in river water (Mehmood et al. 2013).

The second factor represents the role of ecological response of aquatic ecosystem as a source of variability in water physico-chemistry. Temperature, DO, and pH showed high loadings on this factor. DO and pH are factors that are quite sensitive to water pollution, hence greatly vary under the influence of other environmental factors (Wang et al. 2007). Factor 2 showed high scores of moderately polluted sites (cluster-2) located in the river

downstream, which suffer from hyper eutrophic conditions (Nazeer et al. 2014) (Fig. 5). Midstream catchment of river enriches the river with nutrients through sewage pollution and urban and agriculture runoff, which creates hyper eutrophic conditions at river downstream. Primary productivity of the river is increased by eutrophication and subsequently increased the photosynthetic process which releases oxygen. The role of eutrophication as a source of variability also has been discussed earlier for other rivers (Zhao and Cui 2009). Due to climatic variability in the study area, downstream catchment of the river has relatively high temperature compared with upstream and midstream zones. The association of DO and temperature along second axis corresponds to increase in organic pollution and subsequent algal growth from upstream to downstream, which coincides with the longitudinal gradient in temperature. Factor analysis also revealed close association with pH. High photosynthetic activity of algal communities consumes carbon dioxide and raises the water pH (Chandra et al. 2014). Nutrients showed weak negative loadings on this factor, which is due to the conversion of nutrients into phytoplankton biomass (Table 3).

Factor 3 has high loadings of Cu and Fe along with moderate loadings of COD, Cd, ammonia, orthophosphates, and Ni. Source profile of factors 3 showed high scores in urban midstream (cluster-3), which showed the role of urbanization in contribution of those physico-chemical parameters associated with factor 3 (Table 3; Fig. 5). In freshwater, copper form non-labile soluble complexes with Fe, which has mainly origin of parent rock material, whereas ammonia and chlorides also form stable ligands with copper. Concentrations of Fe and Cu were particularly high during post-monsoon as determined through temporal DFA analysis. It was discussed earlier that intense monsoon precipitation transports various contaminants from terrestrial ecosystem to aquatic ecosystem through surface runoff. Hence, Fe and Cu also could be contributed to Soan basin through surface runoff. On the basis of aforementioned reasons, the factor 3 could be termed as urban runoff factor. Livestock farming, leachate from dumps of both industrial and domestic solid waste, and road runoff constitute the urban runoff. In urban runoff, Cu mainly comes from domestic wastewater, combustion process, corrosion, leaching of plumbing, fungicides, wood preservatives, and antifouling agents. Moderate loadings of COD and NH_3 indicate the presence of organic matter in association with other contaminants (Ndungu et al. 2014).

High loadings of nitrates on the fourth factor indicate the role of agriculture runoff. Agrochemical runoff, industrial effluents, municipal landfills, livestock waste, and atmospheric deposition constitute the major sources of nitrates in surface water (Kotti et al. 2005; Chen et al. 2013). Factors 4 represents the impact of agriculture activities on water quality and showed the high scores of suburban part of midstream and downstream sites, which have agriculture as main catchment land use (Table 3; Fig. 5). In River Soan, nitrates are mainly added by agrochemicals and regional geology through diffuse sources, whereas sewage and industrial waste partly contribute to nitrate loadings of river (Jalil and Khan 2012). Pb and Cr showed moderate to weak loadings on this factor, which showed the influence of vehicular emission. These findings are consistent with the previous studies in the region which have reported Pb deposition in water at sites located in close vicinity of roads (Ahmed 1998; Mehmood et al. 2013). Abbasi et al. (2013) has reported the common sources of Pb in this region are heavy traffic, industries, and refineries. Atmospheric fallout from vehicular emissions is usually the most important source of Pb in the freshwaters (Qadir et al. 2008, 2013; N' Diaya et al. 2013). Car washing activities in streams and rivers are prominent anthropogenic activities in a suburban part of midstream of River Soan, which also could contribute Pb to freshwater ecosystem.

Turbidity has high loadings on fifth factor and showed the impact of sediment loadings in altering the water quality. High scores for this factor were noted mainly at suburban midstream sites included in cluster-2 (Table 3; Fig. 5). Human settlements and livestock farming are major anthropogenic activities that were performed either in riparian zone or in close proximity of the river at these sites. Grazing in riparian zone is an important factor to increase turbidity either through the bank erosion or instream disturbances by grazing animals. Weak loadings of COD and nitrates on factor 5 could be attributed to animal waste associated with grazing phenomenon (Wan et al. 2014). Moreover, the poultry waste at suburban part of midstream and domestic sewage from rural areas constitute an additional source of pollution (Yan et al. 2015). Construction activities in new housing societies and dumping of construction waste along the river bank also might be responsible for fluvial transport of sediments (Babar et al. 2014). Moderate association of COD with turbidity on factor 5 might be attributed to the sewage waste discharge. Sewage waste of these housing societies is drained directly into river without any prior treatment. Because the area is not properly developed and hence the population density is low, consequently the impact of urbanization is not as strong as experienced in urban part. Sixth factor has high loadings of Zn (Table 3; Fig. 5). Galvanizing units operating in the region most likely attributed for release of Zn in the air, which entered freshwaters through atmospheric deposition (Pak EPA 2006).

Sewage discharge along with natural processes, such as mineralization of parent rock material, was attributed for enrichment of river with nutrients, macroelements, heavy metal, and organic pollution. Surface runoff from urban areas was attributed for adding macroelements, organic pollution, and heavy metals. Agriculture runoff has appeared to be main role in adding nutrients to the river; however, heavy metals and organic pollution also might contribute to agriculture activities. Livestock interruptions and bank erosion have a main role in adding nutrients and increasing organic load of the river. Industrial activities seemed to be affecting water quality mainly by adding heavy metals.

Conclusion

Spatiotemporal variation in water of River Soan was analyzed using multivariate analysis. Results revealed that spatial heterogeneity in water quality is primarily related to anthropogenic activities concomitant to urbanization. Temporal variations in water quality showed the influence of monsoon precipitation, which mobilizes different contaminant from terrestrial environment to regional water

bodies. Multivariate techniques identified six main sources for causing variations in water quality, which includes mineralization of parent rock material, sewage waste, overgrowth of phytoplankton, urban and agrochemical runoff, physical disturbances at river channels, riparian zone, and at its catchments and industrial activities.

To address the issues linked with water-quality deterioration, the installation of wastewater treatment plants is inevitable. A wastewater treatment plant for treatment of wastewater from Islamabad was made functional in 2009, a year subsequent to duration that the study was conducted. This treatment plant is provided with primary treatment facility for sewage wastewater from different sectors of Islamabad. Wastewater is passed through settling and aeration tanks before its discharge into mainstream of Nallah Lei. The performance of the treatment plant has been severely affected by discontinuous electric power supply. Iram et al. (2013) have reported water quality data of Nallah Lei after the installation of the treatment plant. The concentrations of Ca (75 mg/L) and sulphates (20 mg/L) measured at Nallah Lei by Iram et al. (2013) was lower than present study (Ca: 113 mg/L and sulphates: 61 mg/L), whereas no considerable change was noted for other parameters, such as Pb, Cr, Zn, specific conductivity, and nitrates. To restore water quality, installations of more treatments plants are needed particularly at those sites where sewage drains fall in river mainstream. Furthermore, restoration of riparian buffer zones along the river and effective solid management practices also are needed to cope with diffuse sources of pollution. Likewise livestock farming also needs effective measures like proper handling of silage and slurry and effective utilization of livestock waste as manure.

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