

Water quality assessment of river Beas, India, using multivariate and remote sensing techniques

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Abstract River Beas originates in the Himalayas and merges into river Sutlej at Harike, a Ramsar wetland. This river is a habitat of the endangered freshwater dolphin, *Platanista gangetica minor* R. Twenty-five water quality parameters, including eight heavy metals, were studied at four sampling sites over a stretch of 63 km between Beas and Harike towns for pre-monsoon, post-monsoon and winter seasons. Principal component analysis of the data proved to be an effective tool for data reduction as the first three principal components of all the water quality parameters explained 100 % variance. Factor analysis delineated three factors underlying the water quality. Factor 1 comprised pollution-related parameters like BOD, COD, DO, PO_4^{-3} and hardness. Factor 2 was a natural water quality determinant and explained maximum variance in turbidity, alkalinity and TDS. Factor 3 comprised NO_3^{-1} , a fertilizer-related parameter. Reflectance values from bands 2 (green), 3 (red) and 4 (near infra-red) of Landsat (TM) digital data were regressed on PO_4^{-3} , turbidity and TDS using multiple linear regression analysis. PO_4^{-3} contributed positively to the spectral radiance, whereas TDS contributed negatively. Beta

regression analysis revealed that PO_4^{-3} had a positive relation with BOD, whereas turbidity and TDS were negatively regressed with BOD. Artificial neural network models were fitted to the data. Correlations between the target values from ANN for turbidity, BOD and bands 2 (green), 3 (red) and 4 (near infra-red) were highly significant.

Keywords River Beas · Water analysis · Remote sensing · Multivariate techniques · Neural network analysis

Introduction

Rivers play an important role in controlling the hydrological cycle (Garrels et al. 1975). Rivers carry dissolved or suspended elements and deposit them at different locations (Gaur et al. 2005; Yao and Xu 2013). Several workers (Riedel et al. 2000; Koklu et al. 2010; Akbal et al. 2011; Wan et al. 2013) have assessed the water quality in different rivers. Multivariate statistical techniques such as factor analysis (FA), principal component analysis (PCA), cluster analysis (CA), multiple linear regression analysis (MLR) and artificial neural networks (ANN) are effective analytical tools for water quality assessment (Kuppusamy and Giridhar 2006; Wu and Wang 2007; Chau and Muttill 2007; Chen and Mynett 2006; Alkarkhi et al. 2009). PCA and CA are helpful in the identification of factors that affect the quality of water (Shrestha and Kazama 2007). MLR is used to find out the relationship between one dependent

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and two or more independent variables. Remote sensing (RS) has been used for monitoring and assessment of water quality by various workers (Chopra et al. 2001; Choubey 1992; Kloiber et al. 2002; Nelson et al. 2003). Studies by Alparslan et al. (2007) and Dewidar and Khedr (2001) have shown that DO, pH, total nitrogen, total phosphorus, Na, K and salinity show a good relationship with radiance data from the satellites. Mabwoga and Thukral (2014) reported land use changes in Harike wetland over a span of 21 years. The present study is aimed at physiochemical characterization of water from river Beas between the towns of Beas and Harike in Punjab at four chosen sites and three seasons. Water quality parameters were correlated with reflectance values of bands 2 (green, G), 3 (red, R) and 4 (near infrared, NIR). The study finds its importance in the fact that *Platanista gangetica minor* R., a freshwater river endangered dolphin, is found only in this river (Khan 2013). Recently, about 12 dolphins were sighted in this river (Rana 2013).

Study area

River Beas originates in the Himalayas in central Himachal Pradesh, India, at 31.51' N lat., 77° 05' E long. and altitude 2050 m above sea level, and flows for about 470 km to merge with river Sutlej. The study area comprised a 63-km stretch of the river between the towns of Beas and Harike. The river on its either side has wild growth followed by agricultural fields. The villages around the river dump their sewage and solid wastes into the river. On the basis of approachability to the river, samples were collected from the river adjoining the following towns (Fig. 1):

1. Beas (31.510' N, 75.305' E and 211 m asl): Located in district Amritsar, the town is the headquarters of a religious sect, *Radha Soami*. Every year, millions of pilgrims come to Beas.
2. Kishanpura (31.409' N, 75.189' E and 219 m asl): Located in the Kapurthala district, it is a major agriculture area in this region.
3. Goindwal Sahib (31.376' N, 75.162' E and 217 m asl): Located in the Tarn Taran district, a thermal power plant is located on the banks of river Beas.
4. Harike (31.150' N, 74.951' E and 210 m asl): Harike is located at the confluence of the rivers Beas and Sutlej. It has its boundaries with Amritsar,

Ferozepur and Kapurthala districts. It is one of the international Ramsar wetlands and has a wildlife sanctuary.

Materials and methods

Satellite imagery

Landsat (TM) data dated 7 June 2013, 14 October 2013 and 26 February 2014 were obtained from the U.S. Geological Survey (USGS) (<http://glovis.usgs.gov/>). Erdas Imagine 11 and Arc GIS 9.3 software were used for the processing of the images. An eTrex Garmin Global Positioning System (GPS) receiver was used to determine the geo-coordinates of the study sites. The images were geometrically rectified with reference to the ground control points collected from the field with the help of a GPS receiver. Geo-coordinates along the river were recorded and converted into shape files using Erdas Imagine software from which a base map was prepared. The image was subset to extract the area of study which was used for further analyses. Reflectance values from three bands (G, R and NIR) of the satellite imagery were extracted from the image. The wavelengths of the bands used for the study were G (0.53–0.61 μm), R (0.63–0.69 μm) and NIR (0.78–0.90 μm). The other specifications of the images were spatial resolution (30 m), temporal resolution (16 days), radiometric resolution (8 bits) and swath width of 185 km.

Water sampling and analysis

Water samples were collected on May 30, 2013, October 10, 2013 and February 20, 2014 between 8 am and 11 am from the sites in triplicate. The collection, preservation and analysis of the water samples were carried out as prescribed in the standard methods (APHA 2005). pH was tested using a SDFCL micro pH Analytica pH meter. The temperature of the river water was measured in situ at a depth of 5 cm. Turbidity was measured with a portable turbidity meter (PC compact turbidity meter, Aqualytic). Electrical conductivity was determined by conductivity meter (Systronics, Model 304). TDS was determined by HM digital portable TDS meter.

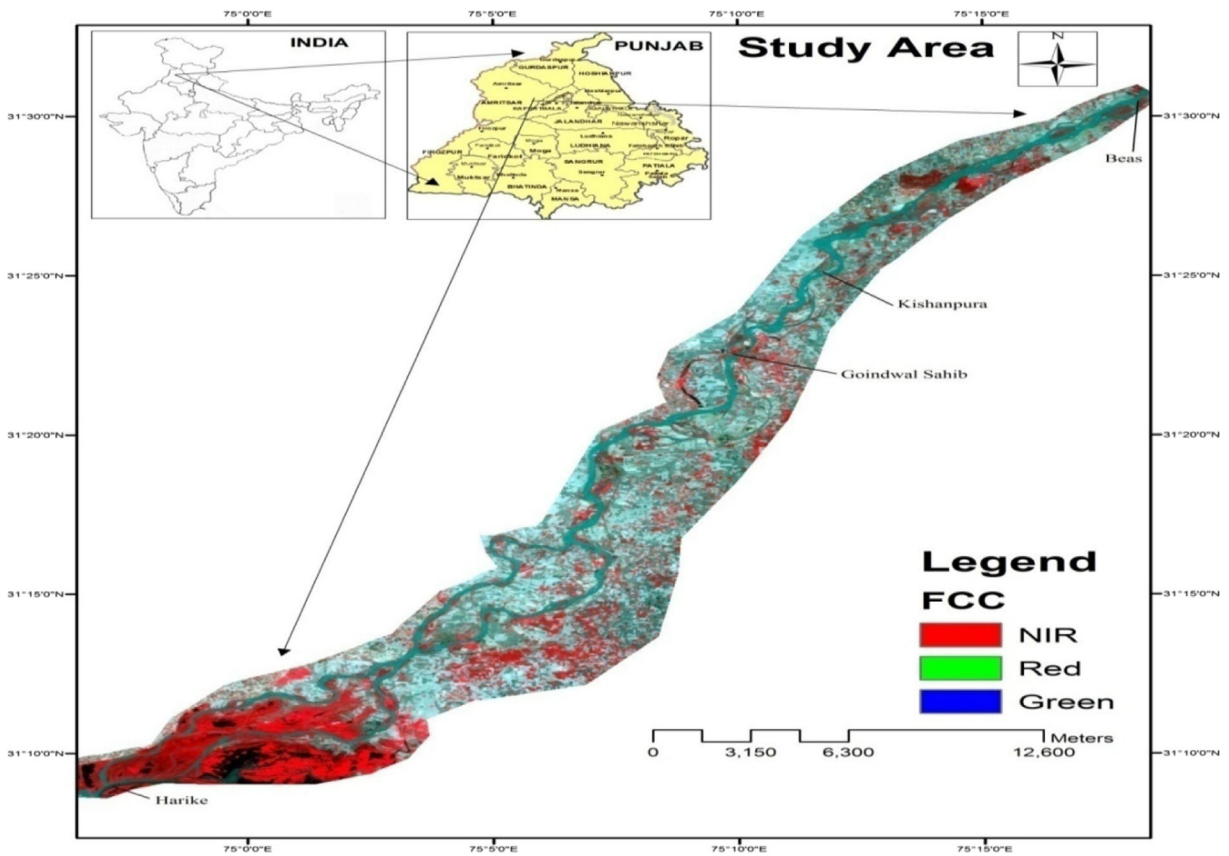


Fig. 1 Location of study area

BOD was determined by 5-day BOD test at 20 °C. COD was estimated by using the closed reflux titrimetric method. DO was determined by azide modification technique. NO_3^{-1} was determined using spectrophotometric method at 220 nm (Thermo, Genesys 10 UV). Hardness and alkalinity were determined by EDTA titrimetric method and titration method respectively. Cl^{-1} determination was done by argentometric method. Na and K were estimated using (Systronics flame photometer-128). Ca and Mg were determined by using EDTA titration method. Water samples were fixed with HNO_3 and filtered with Whatman #1 filter paper for heavy metal analysis using atomic absorption spectrophotometry (Agilent Technologies 200 - Series AA).

Multivariate statistical methods

One-way and two-way analysis of variance (ANOVA) and Tukey’s multiple comparison test were applied to

find honestly significant difference (HSD at $p \leq 0.05$), for 25 water quality parameters (Beaver et al. 2012; Sokal and Rohlf 1995). The null hypothesis tested was that at least two means are significantly different from each other. The heavy metals which were not detected or had very low concentrations were not used for multivariate analysis. Cluster analysis for 21 water quality parameters was performed using Euclidian distance as a measure of distance. Principal component analysis for 19–23 water quality parameters for pre-monsoon, post-monsoon and winter seasons was performed to determine the principal components which explain maximum variance of the data. In factor analysis, new factors which cause variations in the physiochemical parameters (11) and metal concentration (4) were extracted by varimax rotation of the PCA.

Multiple linear regression analysis was used to determine the effect of two or more independent variables on a dependent variable. β -regression coefficients are unitless partial regression coefficients which give the relative effects of different independent variables on a

Fig. 2 Artificial neural network

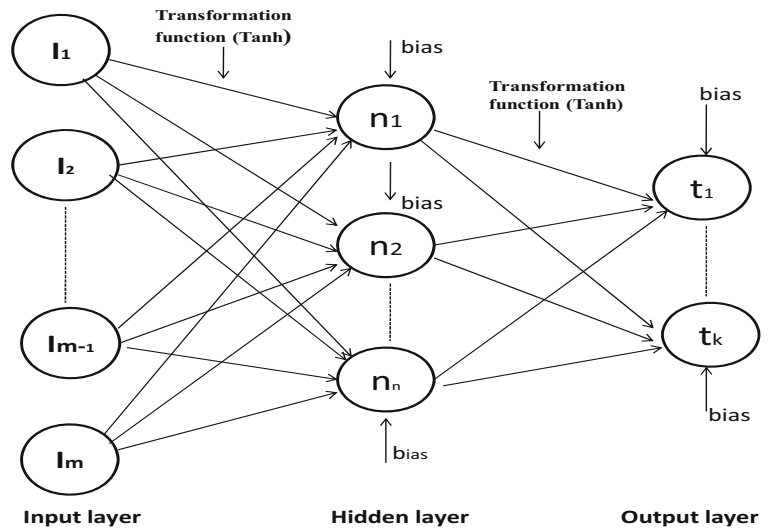


Table 1 One-way ANOVA and multiple comparison test for different water quality parameters from different sites of river Beas for the pre-monsoon season

Parameters	Sites				F ratio ($p < 0.05$)	HSD ($p < 0.05$)
	Beas Mean \pm SD	Kishanpura Mean \pm SD	Goindwal Sahib Mean \pm SD	Harike Mean \pm SD		
pH	8.17 ^a \pm 0.05	7.93 ^{bc} \pm 0.05	8.07 ^{ab} \pm 0.1	7.97 ^{abc} \pm 0.11	4.00*	0.23
Temperature ($^{\circ}$ C)	27.14 \pm 0.15	28.10 \pm 0.10	24.96 \pm 0.15	26.04 \pm 0.05	0.008	ns
Turbidity (NTU)	33.34 ^{ab} \pm 5.68	31 ^{bc} \pm 6.00	43.34 ^a \pm 3.05	43.34 \pm 3.05	6.01*	10.15
Conductivity (μ S cm^{-1})	230 ^{ab} \pm 1.41	226 ^{abc} \pm 5.65	219 ^c \pm 4.24	231.5 ^a \pm 2.12	6.73*	10.88
TDS (mg L^{-1})	108 \pm 6.24	106 \pm 3.60	105.34 \pm 3.21	114.34 \pm 2.08	3.03	ns
BOD (mg L^{-1})	8.06 ^{abc} \pm 0.23	8.34 ^{ab} \pm 0.23	7.27 ^{bc} \pm 0.83	9.14 ^a \pm 0.46	7.01*	1.31
COD (mg L^{-1})	33.34 \pm 11.54	26.67 \pm 11.54	60 \pm 20.00	73.34 \pm 23.09	4.85*	45.3
DO (mg L^{-1})	7.91 \pm 1.29	8.04 \pm 0.80	6.7 \pm 0.46	6.97 \pm 0.23	2.08	ns
NO_3^{-1} (mg L^{-1})	1.846 \pm 0.27	1.628 \pm 0.14	1.711 \pm 0.07	1.507 \pm 0.10	2.15	ns
PO_4^{-3} (mg L^{-1})	0.08 \pm 0.05	0.11 \pm 0.03	0.06 \pm 0.01	0.12 \pm 0.04	1.4	ns
Hardness (mg L^{-1})	108.67 \pm 7.02	110.67 \pm 3.05	104.67 \pm 8.08	104.67 \pm 5.77	0.686	ns
Alkalinity (mg L^{-1})	113.34 \pm 15.27	126.67 \pm 28.86	140 \pm 20.00	146.67 \pm 20.82	1.38	ns
Cl^{-1} (mg L^{-1})	17.95 ^{bc} \pm 0.81	19.85 ^{ab} \pm 1.42	15.59 ^c \pm 1.41	21.74 ^a \pm 0.81	15.50*	3.02
Na (mg L^{-1})	10.01 \pm 0.33	9.82 \pm 1.30	9.95 \pm 2.20	11.92 \pm 1.54	1.31	ns
K (mg L^{-1})	3.14 \pm 0.07	2.84 \pm 0.50	3.28 \pm 1.44	3.78 \pm 0.38	0.75	ns
Ca (mg L^{-1})	28.31 \pm 0.46	27.78 \pm 0.46	29.38 \pm 2.01	29.92 \pm 1.22	1.901	ns
Mg (mg L^{-1})	9.25 ^{ab} \pm 1.46	10.07 ^a \pm 0.56	7.63 ^{abc} \pm 0.74	7.3 ^{bc} \pm 0.97	5.23*	2.6
Mn (mg L^{-1})	0.11 \pm 0.003	0.13 \pm 0.001	0.002 \pm 0.001	0.124 \pm 0.05	0.43	ns
Cr (mg L^{-1})	0.006 \pm 0.001	0.012 \pm 0.006	0.009 \pm 0.005	0.004 \pm 0.001	3.27	ns
Cu (mg L^{-1})	0.011 \pm 0.006	0.009 \pm 0.001	0.003 \pm 0.002	0.006 \pm 0.004	1.04	ns
Co (mg L^{-1})	0.006 \pm 0.001	0.008 \pm 0.003	0.012 \pm 0.001	0.013 \pm 0.005	3.32	ns

Same superscript or no superscript letter in a row indicates no significant difference between the means at $p < 0.05$

ns not significant at $p < 0.05$, Zn, Ni, Hg and As; - not detected or below detection limit

*indicates significant at $p < 0.05$

Table 2 One-way ANOVA and multiple comparison test for different water quality parameters from different sites of river Beas for the post-monsoon season

Parameters	Sites				F ratio ($p < 0.05$)	HSD ($p < 0.05$)
	Beas Mean \pm SD	Kishanpura Mean \pm SD	Goindwal Sahib Mean \pm SD	Harike Mean \pm SD		
pH	7.86 ^a \pm 0.06	7.71 ^{ab} \pm 0.05	7.53 ^c \pm 0.04	7.32 \pm 0.07	45.59*	0.15
Temperature ($^{\circ}$ C)	23.70 ^{bc} \pm 0.20	25.00 ^{abc} \pm 0.10	24.77 ^{ab} \pm 0.05	25.86 ^a \pm 0.05	168.31*	0.31
Turbidity (NTU)	59.34 ^c \pm 5.13	110.67 ^{ab} \pm 16.25	56.34 ^c \pm 17.03	131.00 ^a \pm 7.00	26.54*	32.82
Conductivity (μ S cm^{-1})	150.00 \pm 10.00	160.00 \pm 10.00	156.67 \pm 5.77	156.67 \pm 5.77	0.79	ns
TDS (mg L^{-1})	160.00 \pm 21.79	179.34 \pm 11.01	178.34 \pm 12.58	177.34 \pm 15.53	1.02	ns
BOD (mg L^{-1})	5.64 ^b \pm 0.12	8.12 ^a \pm 0.94	5.89 ^{bc} \pm 0.45	4.79 ^{bc} \pm 0.29	20.04*	1.43
COD (mg L^{-1})	80.00 \pm 40.00	53.34 \pm 23.09	66.67 \pm 23.09	66.67 \pm 46.18	0.29	ns
DO (mg L^{-1})	5.90 \pm 0.61	6.16 \pm 0.23	6.55 \pm 0.59	5.35 \pm 0.21	3.67	ns
NO ₃ ⁻¹ (mg L^{-1})	2.70 ^a \pm 0.047	1.44 ^b \pm 0.14	1.47 ^b \pm 0.11	0.92 \pm 0.23	73.31*	0.39
PO ₄ ⁻³ (mg L^{-1})	0.028 \pm 0.025	0.036 \pm 0.018	0.024 \pm 0.004	0.031 \pm 0.013	0.25	ns
Hardness (mg L^{-1})	76.00 ^{bc} \pm 2.00	80.00 ^{bc} \pm 5.29	84.00 ^{ab} \pm 2.00	94.00 ^a \pm 5.29	11.18*	10.46
Alkalinity (mg L^{-1})	105 ^c \pm 5.00	111.67 ^{bc} \pm 2.88	118.34 ^{ab} \pm 2.88	122.34 ^a \pm 2.51	14.51*	9.05
Cl ⁻¹ (mg L^{-1})	21.27 ^{bc} \pm 1.41	20.32 ^{bc} \pm 2.16	27.88 ^a \pm 2.95	24.57 ^{ab} \pm 0.81	8.83*	5.24
Na (mg L^{-1})	19.84 ^{bc} \pm 2.36	23.20 ^{ab} \pm 1.25	18.26 ^c \pm 0.45	24.90 ^a \pm 0.96	13.30*	3.77
K (mg L^{-1})	31.24 \pm 1.06	32.50 \pm 1.22	31.50 \pm 1.55	32.87 \pm 2.32	0.7	ns
Ca (mg L^{-1})	66.26 ^a \pm 3.64	60.35 ^{ab} \pm 2.91	45.81 ^c \pm 3.10	39.67 ^c \pm 4.24	37.59*	9.15
Mg (mg L^{-1})	17.14 \pm 5.50	18.31 \pm 2.57	15.85 \pm 1.41	15.37 \pm 1.20	0.52	ns
Zn (mg L^{-1})	0.046 \pm 0.022	0.045 \pm 0.026	0.017 \pm 0.007	0.017 \pm 0.007	2.506	ns
Mn (mg L^{-1})	0.61 ^c \pm 0.008	3.61 ^a \pm 0.072	1.29 ^b \pm 0.015	0.59 ^c \pm 0.019	3804.74*	0.1
Cr (mg L^{-1})	0.048 ^b \pm 0.015	0.079 ^a \pm 0.007	0.021 ^c \pm 0.005	0.008 ^c \pm 0.002	36.90*	0.02
Cu (mg L^{-1})	0.01 \pm 0.014	0.029 \pm 0.012	0.0024 \pm 0.002	0.024 \pm 0.022	2.1	ns
Co (mg L^{-1})	0.0006 \pm 0.001	0.0006 \pm 0.001	–	0.0006 \pm 0.001	0.0	ns

Same superscript or no superscript letter in a row indicates no significant difference between the means at $p < 0.05$

ns not significant at $p < 0.05$, Ni, Hg, and As; – not detected or below detection limit

dependent variable. The artificial neural network consists of an input layer, one or more hidden layers of neurons and an output layer. The ANN model was developed between water quality parameters and reflectance values in bands 2 (G), 3 (R) and 4 (NIR) using the Statistica-12 software. The number of neurons was selected by the software when the maximum variance was explained. It is generally 70 to 90 % of the size of the input layer (Boger and Guterman 1997). The options selected were multilayer perceptron, 1000 iterations, ten neurons and tanh transfer function, both at the input layer and the hidden layer. ANN models were also developed between BOD, turbidity and water quality parameters (Fig. 2). Software used for calculations was Microsoft Office Excel-2007, Statistica-12, Minitab-14, PAST and self-coded software.

Results and discussion

Tables 1, 2 and 3 give water quality parameters in the river water samples collected from different sites. Differences among the means of BOD and pH were found to be significant for all the three seasons. The pH of the water was neutral to slightly alkaline. Variations in Cl⁻¹ were found to be significant during the post-monsoon and pre-monsoon seasons. Mg levels were significantly different between the winter and pre-monsoon seasons. Na and Mn differences were found to be significant during the post-monsoon and pre-monsoon seasons. Turbidity, NO₃⁻¹, hardness, Ca and Cr showed significant variations during the post-monsoon season. Concentration of K varied significantly during the winter season, whereas conductivity and COD

Table 3 One-way ANOVA and multiple comparison test for different water quality parameters from different sites of river Beas for the winter season

Parameters	Sites				F ratio ($p < 0.05$)	HSD ($p < 0.05$)
	Beas Mean \pm SD	Kishanpura Mean \pm SD	Goindwal Sahib Mean \pm SD	Harike Mean \pm SD		
pH	7.21 ^c \pm 0.073	7.25 ^{bc} \pm 0.047	7.40 ^{ab} \pm 0.052	7.54 ^a \pm 0.098	13.08*	0.18
Temperature ($^{\circ}$ C)	13.77 ^c \pm 0.25	14.14 ^b \pm 0.15	14.47 ^{ab} \pm 0.20	14.74 ^a \pm 0.152	13.70*	0.51
Turbidity (NTU)	48.67 \pm 4.04	60.67 \pm 14.57	74.34 \pm 3.51	70.00 \pm 17.69	2.79	ns
Conductivity (μ S cm^{-1})	314.50 \pm 3.53	315.50 \pm 0.70	313.00 \pm 2.82	307.67 \pm 2.08	1.66	ns
TDS (mg L^{-1})	222.67 \pm 3.78	219.67 \pm 2.08	218.00 \pm 6.08	216.34 \pm 1.52	1.5	ns
BOD (mg L^{-1})	12.05 ^{ab} \pm 1.29	12.74 ^a \pm 1.5	9.49 ^{abc} \pm 1.56	7.24 ^c \pm 0.57	11.36*	3.38
COD (mg L^{-1})	33.34 \pm 11.54	26.67 \pm 11.54	26.67 \pm 11.54	53.34 \pm 11.54	3.58	ns
DO (mg L^{-1})	8.31 \pm 0.22	8.45 \pm 0.39	7.51 \pm 0.61	7.78 \pm 0.46	2.88	ns
NO ₃ ⁻¹ (mg L^{-1})	1.96 \pm 0.23	2.18 \pm 0.18	2.07 \pm 0.06	1.87 \pm 0.04	2.26	ns
PO ₄ ⁻³ (mg L^{-1})	0.081 \pm 0.023	0.107 \pm 0.05	0.123 \pm 0.014	0.072 \pm 0.013	1.92	ns
Hardness (mg L^{-1})	102.67 \pm 5.03	104 \pm 2.00	108 \pm 2.00	108 \pm 4.00	1.83	ns
Alkalinity (mg L^{-1})	96.67 \pm 15.27	100 \pm 10.00	100 \pm 10.00	106.67 \pm 5.77	0.45	ns
Cl ⁻¹ (mg L^{-1})	7.95 \pm 0.29	8.46 \pm 0.95	8.27 \pm 1.09	7.82 \pm 0.10	0.46	ns
Na (mg L^{-1})	37.30 ^c \pm 1.37	45.63 ^{ab} \pm 1.76	46.53 ^a \pm 1.71	37.03 ^c \pm 1.28	10.23*	3.10
K (mg L^{-1})	31.56 ^{ab} \pm 0.58	29.10 ^{abc} \pm 1.05	27.04 ^c \pm 1.95	31.57 ^a \pm 0.58	33.34*	4.04
Ca (mg L^{-1})	24.74 \pm 1.43	17.57 \pm 2.03	21.54 \pm 5.33	19.58 \pm 5.73	1.65	ns
Mg (mg L^{-1})	10.68 ^c \pm 1.02	10.81 ^c \pm 1.44	15.85 ^a \pm 1.41	15.37 ^{ab} \pm 1.20	14.42*	3.35
Zn (mg L^{-1})	0.0057 \pm 0.006	–	–	0.002 \pm 0.003	0.66	ns
Mn (mg L^{-1})	0.094 ^{bc} \pm 0.007	0.068 ^c \pm 0.03	0.123 ^{ab} \pm 0.005	0.152 ^a \pm 0.022	10.42*	0.05
Cu (mg L^{-1})	0.0044 \pm 0.007	–	–	–	–	–

Same superscript or no superscript in a row indicates no significant difference between the means at $p < 0.05$

ns not significant at $p < 0.05$, Cr, Co, Ni, Hg, and As; – not detected or below detection limit.

*indicates significant at $p < 0.05$

showed significant differences in the means of samples during the pre-monsoon season. Two-way ANOVA between different sites and seasons revealed significant interaction between the sites and the seasons for pH, temperature, turbidity, BOD, NO₃⁻¹, hardness, Cl⁻¹, Na, K, Ca, Mg, Mn, Cr and Co, implying that the trends of variation of parameters change with site and season (Table 4).

Our results are in accordance with Moza and Mishra (2007) who analysed pH, DO, Cl⁻¹ and PO₄⁻³ in water from river Beas at Beas bridge and the Harike lake. The results show slight variations from those of Central Pollution Control Board, New Delhi (2011) for pH, conductivity, DO and BOD in water from river Beas. Increase in dissolved and suspended solids in water increase the biological and chemical oxygen demands (Jonnalagadda and Mhere 2001). Wastewater possesses high concentration of Cl⁻¹ than raw water because NaCl, the common

component of human diet, passes unchanged through the digestive system (WHO 2006). In rivers, the lower content of DO may be due to the microbial activity in water (Palma et al. 2010). BOD is the amount of oxygen required for aerobic bacteria for the oxidation of organic matter present in the waste and is a part of COD (Cieszynska et al. 2012). Large amounts of biodegradable organic compounds affect the quality of surface waters because the organisms use the available DO for breakdown of wastes in the water, and as a result, the supply of oxygen in the water is reduced, thereby affecting the overall quality of water (Carpenter et al. 1998).

The multivariate analysis of water quality parameters of river water has been used for the first time in this region. In cluster analysis, the data from the post-monsoon season formed one group and data from winter and pre-monsoon seasons formed another group. Our

Table 4 Two-way ANOVA for water quality parameters of river Beas

Parameters	F ratios			HSD (*p < 0.05)
	Sites	Seasons	Sites × seasons	
pH	5.66*	251.93*	20.24*	0.22
Temperature (°C)	9.03*	4008.73*	22.17*	1.015
Turbidity (NTU)	18.02*	75.36*	13.15*	30.30
Conductivity (µS cm ⁻¹)	0.95	2277.63*	2.48	16.64
TDS (mg L ⁻¹)	1.21	391.97*	1.08	28.30
BOD (mg L ⁻¹)	17.05*	73.56*	9.54*	2.53
COD (mg L ⁻¹)	2.43	5.43*	0.56	70.09
DO (mg L ⁻¹)	1.85	35.02*	2.33	1.86
NO ₃ ⁻¹ (mg L ⁻¹)	32.86 *	21.71*	20.02*	0.46
PO ₄ ⁻³ (mg L ⁻¹)	0.77	18.49*	1.77	0.09
Hardness (mg L ⁻¹)	2.81	93.43*	3.66*	13.98
Alkalinity (mg L ⁻¹)	3.32*	14.24*	0.50	41.78
Cl ⁻¹ (mg L ⁻¹)	4.96 *	378.80*	11.86*	4.12
Na (mg L ⁻¹)	10.18*	1334.26*	19.50*	4.40
K (mg L ⁻¹)	1.60	1984.30*	4.58*	3.66
Ca (mg L ⁻¹)	16.39*	326.88*	15.64*	9.44
Mg (mg L ⁻¹)	0.27	46.30*	3.92*	6.09
Zn (mg L ⁻¹)	2.79	30.32*	2.14	0.035
Mn (mg L ⁻¹)	2233.79*	9045.81*	2331.57*	0.087
Cr (mg L ⁻¹)	38.10*	129.44*	26.87*	0.019
Cu (mg L ⁻¹)	2.07	3.59*	1.97	0.029
Co (mg L ⁻¹)	2.84	93.45*	3.31*	0.006

studies on cluster analysis find support from Gnanamoorthy et al. (2013) who worked on Parangipettai, southeast coast of India, and observed

Table 5 Variance explained in principal component analysis of different water quality parameters of river Beas

Seasons	PC1 (%)	PC2 (%)	PC3 (%)
Pre-monsoon season	80.24	16.53	3.22
Post-monsoon season	77.85	17.92	4.23
Winter season	85.29	8.33	6.38

that each season forms a separate group. PCA generates the number of principal components equal to the number of variables. In the present study, the first three principal components explained 100 % of the total variance for all the seasons (Table 5). COD and alkalinity had maximum loadings during the pre-monsoon season, whereas turbidity, COD and alkalinity had maximum loadings during the post-monsoon season. In the winter season, maximum loadings were on turbidity, COD and Na. Results of factor analysis are presented in Table 6. Factor 1 accounted for 46 % of the total variance and had strong positive loadings on conductivity, DO, PO₄⁻³ and hardness, and strong negative loadings on BOD, COD and Cl⁻¹. Since all these parameters are pollution related from sewage and domestic wastewater, the first

Table 6 Factor analysis of different water quality parameters of river Beas

Physiochemical characteristics				
Variables	Factor 1	Factor 2	Factor 3	Communality
Turbidity	-0.40	-0.71	0.46	0.88
Conductivity	0.88	0.38	0.19	0.96
TDS	0.10	0.94	-0.12	0.92
BOD	-0.80	-0.21	0.27	0.76
COD	-0.80	-0.15	-0.19	0.71
DO	0.83	0.12	0.43	0.89
NO ₃ ⁻¹	0.02	0.36	0.87	0.90
PO ₄ ⁻³	0.83	-0.19	0.22	0.79
Hardness	0.95	-0.21	-0.03	0.96
Alkalinity	-0.06	-0.90	-0.28	0.90
Cl ⁻¹	-0.71	-0.56	-0.23	0.88
Variance	5.07	2.7	1.82	9.6
% var	46 %	24 %	16 %	86 %
Variables	Factor 1	Factor 2	Communality	
Na	0.92	0.35	0.97	
K	0.90	-0.35	0.94	
Ca ²⁺	-0.05	-0.98	0.96	
Mg ²⁺	0.68	-0.67	0.92	
Variance	2.13	1.67	3.80	
% var	53 %	41 %	94 %	
Reflectance values	Factor 1	Factor 2	Communality	
Green	0.78	0.62	0.99	
Red	0.83	0.54	0.99	
NIR	0.56	0.82	1.00	
Variance	1.63	1.36	2.99	
%var	54 %	45 %	99 %	

Table 7 Multiple linear regression between reflectance values or BOD and independent variables

Equations

Band2 (G) = 64.93 + 150.66 PO₄⁻³ (mg L⁻¹) + 0.002 turb (NTU) - 0.19 TDS (mg L⁻¹) $\beta_1 = 0.48, \beta_2 = 0.005, \beta_3 = -0.77; r = 0.943$ ($p < 0.001$)

Band3 (R) = 82.58 + 167.73 PO₄⁻³ (mg L⁻¹) + 0.002 turb (NTU) - 0.27 TDS (mg L⁻¹) $\beta_1 = 0.39, \beta_2 = 0.004, \beta_3 = -0.83; r = 0.946$ ($p < 0.001$)

Band 4 (NIR) = 53.05 + 187.82 PO₄⁻³ (mg L⁻¹) - 0.09 turb (NTU) - 0.15 TDS (mg L⁻¹) $\beta_1 = 0.52, \beta_2 = -0.20, \beta_3 = -0.55; r = 0.938$ ($p < 0.001$)

BOD (mg L⁻¹) = 2.56 + 37.18 PO₄⁻³ (mg L⁻¹) - 0.023 turb (NTU) - 0.026 TDS (mg L⁻¹) $\beta_1 = 0.587, \beta_2 = -0.287, \beta_3 = -0.521; r = 0.825$ ($p < 0.01$)

Beta regression coefficients: β_1 (PO₄⁻³), β_2 (turbidity) and β_3 (TDS); multiple correlation coefficient = r

factor is largely a pollution loading factor leading to eutrophication. Factor 2 accounted for 24 % of the total variance and had strong loadings on TDS, alkalinity and turbidity due to the natural quality of water and industrial pollutants. Factor 3 accounted for 16 % of the total variance and had strong positive loadings on NO₃⁻¹. This factor indicates the influence of NO₃⁻¹ fertilizers used in agriculture dominated the catchment area of the river. In case of metal analysis, factor 1 accounted for 53 % of the total variance and had strong loadings on Na, K and Mg. This factor indicates the influence of domestic pollutants. The contribution of Na and K to this factor may be attributed to cation exchange processes in the soil-water interface (Guo and Wang 2004). Factor 2 accounted for 41 % of the total variance and had strong loadings on Ca.

Multivariate analysis of spectral radiance in relation to water quality parameters revealed that the reflectance values in three bands, 2 (G), 3 (R) and 4 (NIR), are governed by two factors (Table 6). Factor 1 had maximum loadings on bands 2 (G) and 3 (R), and this factor is mainly due to abiotic components. Factor 2 had maximum loadings on band 4 (NIR), and this factor may be attributed to green algae and other plants present in the water. Mabwoga et al. (2010) worked on water quality parameters in Harike wetland, and reported that turbidity shows correlation with the reflectance data. Our findings are in conformation with Coskun et al. (2008) on drinking water of Omerli reservoir. PO₄⁻³ is an indicator of pollution which enters into the river through domestic wastewater and causes eutrophication. Turbidity may be caused by two factors, i.e., sand and silt carried by water from the mountains and sewage and industrial effluents discharged into the river. TDS mainly consists of inorganic salts such as Na,

K, PO₄⁻³, NO₃⁻¹, Ca, Mg, SO₄⁻², Cl⁻¹, etc. and lesser amount of organic matter. MLR was done between the reflectance values in bands 2 (G), 3 (R) and 4 (NIR) and water quality parameters PO₄⁻³, turbidity and TDS (Table 7). These parameters were selected on the basis of PO₄⁻³ in sewage discharged into the river, turbidity due to physical and biological phenomena, and TDS due to industrial and agricultural water discharges. It was found from the multiple and β -regression analyses that reflectance in band 2 (G) is decreased due to the TDS content of water, and enhanced due to PO₄⁻³ content of water. Turbidity does not have much effect on reflectance in band 2 (G). Band 3 (R) also gives results similar to band 2 (G). In band 4 (NIR), turbidity decreases the spectral radiance. PO₄⁻³ increases the spectral radiance of all the bands. PO₄⁻³, turbidity and TDS were also regressed on BOD. It was found from multiple and β -regression analysis that the value of BOD is enhanced due to PO₄⁻³ content of water, whereas turbidity and TDS decreased the value of BOD. The ANN model fitted well with the simulated and the observed data. The correlations between target and output values from ANN for BOD (validation: $r=0.926$), turbidity (validation: $r=0.995$) and reflectance values in bands 2 (G) (validation: $r=0.999$), 3 (R) (validation: $r=0.998$) and 4 (NIR) (validation: $r=0.999$) were highly significant ($p < 0.001$).

Conclusions

The results suggested that domestic, industrial and agricultural activities have significant effect on the water quality parameters in river Beas. The water quality of the river deteriorates as it flows down from Himachal

Pradesh to Punjab. Parameters having significant influence are BOD, DO, COD, TDS, turbidity, conductivity, hardness, PO_4^{-3} , NO_3^{-1} , Cl^{-1} , Ca, Na and K. In the present study, reflectance values in FA revealed two underlying factors. Factor 1 comprised the abiotic components, and factor 2 comprised green algae and other plants present in the water. Cluster analysis showed that water quality parameters of each season form a separate group. PO_4^{-3} contributed positively to the reflectance values of all the bands, whereas TDS contributed negatively. PO_4^{-3} contributed positively to the BOD, whereas turbidity and TDS contributed negatively. ANN can be used to stimulate water quality parameters using reflectance values. The study warrants that appropriate water pollution prevention measures should be taken to treat the domestic and industrial wastewater, before it flows down to the river. This will help in protecting the endangered biodiversity of the river and the Harike wetland.

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