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WATER QUALITY ASSESSMENT OF DOON VALLEY STREAMS USING MULTIVARIATE STATISTICAL ANALYSIS

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Abstract: The present study highlights the utilization of multivariate statistical methods as a tool for water quality assessment. It was carried out using multivariate statistical techniques to analyze the quality of water and monitoring the variables affecting the water quality of streams of Doon Valley. 15 physical and chemical parameters were sampled at 20 sampling stations set of 5 Rivers in East and West for two years (March, 2012-February, 2014). Results of these measurements were analyzed by multivariate procedures such as Pearson Product Moment Coefficient of Correlation (PPMCC) and Factor Analysis (FA) to understand the interrelationship of water quality parameters amongst themselves. This study illustrated the usefulness of multivariate statistical techniques for analysis and interpretation of complex data sets in water quality assessment, identification of pollution sources/factors and understanding spatial variations in water quality for effective river water quality management.
Keywords: Water quality, Doon Valley, Factor Analysis, Pearson Coefficient of Correlation.
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INTRODUCTION

Water quality depends on a variety of physico-chemical parameters and meaningful prediction. Ranking analysis or pattern recognition of the quality of water requires multivariate projection methods for simultaneous and systematic interpretation (Ayoko *et al*., 2007). Multivariate statistical techniques are used to interpret the water quality of the study area and to give meaningful results that were not possible while assessing the data at a glance (Khan, 2011). The multivariate analysis is used in making the relationship between variables (water quality data). This technique aims to transform the observed variables to a set of variables, which are uncorrelated and arranged in decreasing order of importance. The principal aim is to simplify the problem and to find new variables (principal components), which make the data easier to understand (Mazlum *et al*., 1999). The result of these techniques helps the interpretation of the data. The numbers of factors, called Principal Components (PC), were defined according to the criterion that only factors that account for variance greater than 1 (eigen value- one criterion) should be included. The rotation process in FA allows flexibility by presenting a multiplicity of views of the same dataset (Andrade et al 2008). Works using statistical tools (software) like Principal Component Analysis (PCA), Factor Analysis (FA), a comparatively less quantum of work has been initiated in India, except a few (Raghunath *et al.,* 2002; Bhat, 2003, 2004; Singh *et al*., 2004, 2005; Sreekantha *et al*., 2007; Johnson and Arunachalam, 2009; Kumar and Singh, 2010; Khan, 2011; Johnson *et al*., 2012; Gupta *et al*., 2012; Jha *et al*., 2012; Bhatt *et al*., 2012, Rana and Bhatt, 2014). It is an established fact that to keep the aquatic habitat favourable for existence of fish and other biota, physical and chemical factors of water exercise their influence individually or synergistically. Therefore, assessment of water quality at various stations in Eastern and Western Doon is an integral part of the present enterprise with a view to work out the annual fluctuation regime in water quality parameters and to estimate their impact on the fish population dwelling therein.

EXPERIMENTAL

Doon Valley, part of district Dehradun (latitude – 29°58' and 30°32' N and longitude – 77°35' and 78°20'E) comprises of 2 main river basins, namely, the Ganga river basin and the Yamuna river basin (Figure 1). The present study was carried out on these two river systems comprising of five main rivers - Baldi, Song, Suswa, Tons and Asan. Sampling was regularly/periodically done for a period of 24 months (March, 2012 – February, 2014) at the 20 sampling stations established along the rivers mentioned above (Figure 2). The estimation of physical like Depth (D), Width (W), Water Velocity (WV), Air Temperature (AT), Water Temperature (WT) and chemical parameters like Dissolved Oxygen (DO) in mg/*l*, Carbon dioxide (CO_2) in mg/*l* and pH were firstly analyzed in the field with the help of field water and soil analysis kit. Secondly, the parameters which could not be analyzed in the field viz., Hardness (Hd.) in mg/*l*, Alkalinity (Alk.) in mg/*l*, Turbidity (Turb.) in JTU, Biological Oxygen Demand (BOD) in *ppm*, Nitrates (N) in *ppm*, Phosphates (P) in *ppm* and Total Dissolved Solids (TDS) in *ppm* were analyzed in the laboratory by following standard methods (Trivedy and Goel, 1984; APHA, 2005). Simultaneously, water samples were also submitted to the Central laboratory of Central Soil and Water Conservation Research and Training Institute (CSWCRTI), Dehradun and Central Pollution Control Board (CPCB), Dehradun for verifying the data procured/analyzed in the field/laboratory before reaching to any final conclusion.

To accomplish Pearson Product Moment Coefficient of Correlation (PPMCC) the data matrix regarding the water quality parameters recorded for all the stations of different rivers was put to statistical calculations. The correlation computed between different physico–chemical variables was obtained in a tabular form, indicating the numerical values ranging from -1.0 – +1.0. A positive (+ve) value *i.e.*, > 0.0 is indicative of positive correlation and higher the values, the stronger the correlation. Similarly, a negative (-ve) value < 0.0 indicates negative correlation and the lower the value the stronger is the correlation (Tables 1 and 2). To accomplish Factor Analysis (FA), the data regarding water quality recorded at various sampling stations in the form of a data matrix was put to software analyses using STATISTICA 2001 software, as a result of which the variables (water quality parameters) got fractionated into Factors and each Factor is held specified by a set of water quality parameters showing either highest +ve or -ve loadings. Thus, variables with high absolute loadings (either +ve or -ve) concerning with a Factor contribute strongly to that Factor. After statistical application of the data, the Factors thus generated are presented in a Tabular form (Tables 3 and 4) where the scores mentioned against every parameter (variable) figure under the column of Factors generated. To present the Factor Analysis results eigen values, loading factors (at ≥ 0.70) highlighted in the Tables 3 and 4 are considered for interpretations of the results. The loading value scores thus presented in the Tables (*vide* Tables 3 – 4) will be highlighted (boldened) for those having scores ≥ 0.70, whether showing +ve or -ve loadings.

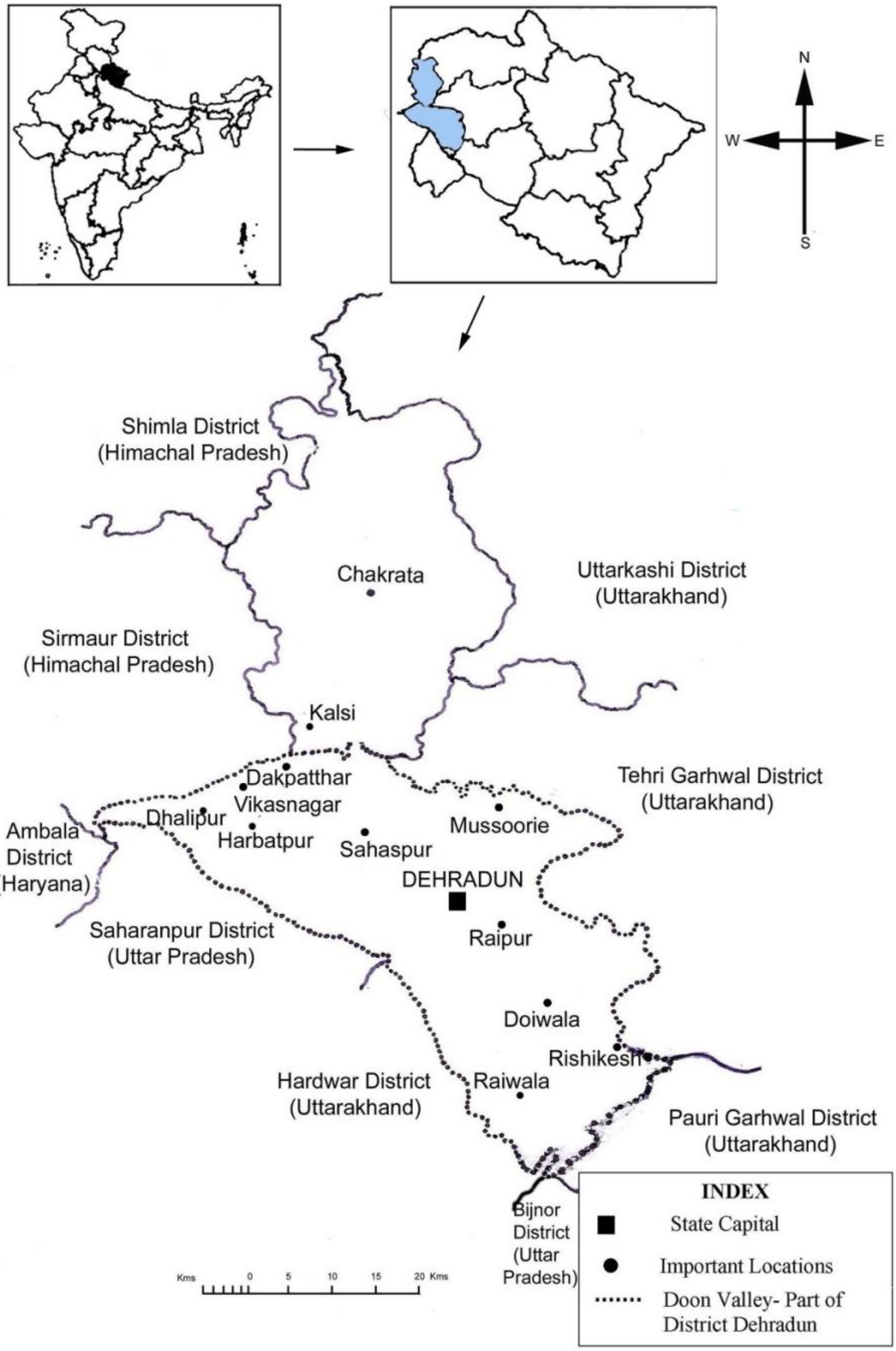

Figure 1. Location of the study area

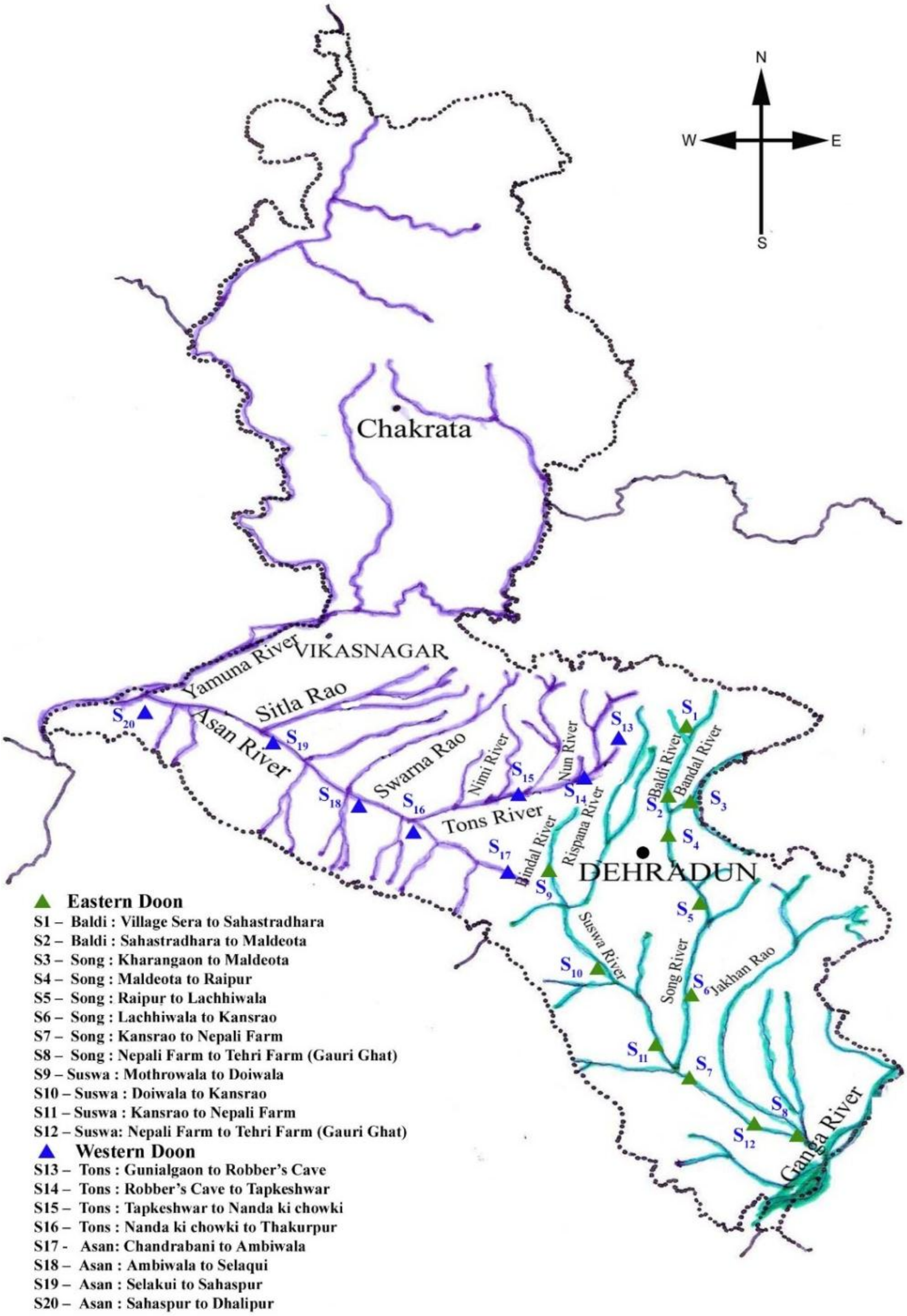

Figure 2. Study area showing sampling stretches in Eastern and Western Doon

RESULTS AND DISCUSSION

PPMCC of 15 water quality variables was deduced separately, for Eastern and Western Doon, using station-wise and month-wise data. The results were obtained in the form of correlation matrix (Tables 1 and 2) with correlation values (*r*) indicating the strength of coherence between any 2 water quality variables. On the basis of coefficient correlation (*r*) values, 7 categories *viz*., strong +ve (r = ≥+0.50), strong - ve(r = ≥-0.50), moderate

+ve(*r* = ≥+0.30), moderate -ve(*r* = ≥-0.30), low +ve(*r* = ≥+0.10), low -ve (*r* = ≥-0.10) and none (*r* = 0.0) have been identified. Customarily, to build up an understanding about the water quality in the two regions of Doon valley, only the strong +ve and strong –ve correlations elaborated and discussed at 2 levels of significance (*p*) *i.e.*, 0.05 and 0.01. As per the correlation analysis, 11 combination of parameters exhibit strong +ve correlation (*r* = >0.500 – 0.855) while 7 combinations of parameters express strong -ve correlations (*r* = >- 0.507 — - 0.810). Strong +ve correlation were observed between Turbidity and CO_2 (*r* = 0.855), TDS and Hardness (*r* = 0.761), WV and Turbidity (*r* = 0.747), AT and WT (*r* = 0.733), AT and CO_2 (*r* = 0.699), AT and Turbidity (*r* = 0.643), WV and CO_2 (*r* = 0.584), BOD and Nitrate (*r*= 0.549), Width and Depth (*r* = 0.546), DO and pH (*r* = 0.543), Alkalinity and Hardness (*r* = 0.508) (Table 1).Strong -ve correlation were observed between DO and CO_2 (*r* = - 0.810), AT and DO (*r* = - 0.757), DO and Turbidity (*r* = - 0.668), AT and pH (*r* = - 0.608), Depth and TDS (*r* = - 0.563), Turbidity and pH (*r* = - 0.536), WT and DO (*r* = - 0.507) (Table 1). As compared to 11 of East, 12 water quality parameters exhibited strong +ve correlation (*r* = >0.503 - 0.891), of which 9 combinations like Turbidity and CO_2 (*r* = 0.891), AT and CO_2 (*r* = 0.847), Width and Depth (*r* = 0.820), AT and Turbidity (*r* = 0.796), AT and WT (*r* = 0.782), WV and Turbidity (*r* = 0.770), Alkalinity and Hardness (*r* = 0.736), WV and CO_2 (*r* = 0.700) and Nitrate and BOD (*r* = 0.589) are similar to East but with higher *r* values (Table 2).

Negative correlation, as compared to 7 of East, 9 combinations of parameters exhibited strong '- ve' correlation (*r* = > -0.517 — - 0.905) of which CO2 and DO (*r* = - 0.905), Turbidity and DO (*r* = - 0.794), AT and DO (*r* = - 0.732) and WT and DO (*r* = - 0.558) are similar to East, the former two recording higher '*r*' values. The rest combinations are Width and Hardness (*r* = - 0.666), WV and DO (*r* = - 0.634), Width and Alkalinity (*r* = - 0.620), TDS and DO (*r* = - 0.581), Depth and Alkalinity (*r* = - 0.517). As has been observed through PPMCC discussed, correlation matrix derived (Tables 1 and 2) has been useful in categorically pointing out associations between variables. To verify the results observed through PPMCC, the water quality × locality data matrix was put to Factor Analysis for East and West, separately.

Factor analysis has revealed that only 14 out of 15 water quality stand factorized into 5 Factors identified on the basis of high + ve or - ve loadings *p* ≥ 0.70 (Table 3). The total variance explained by the first 5 Factors is 81.00%. It included Turbidity (0.89) > CO_2 (0.85) > WV (0.84), substantiating the strong +ve correlations (PPMCC) observed between them *viz*., Turbidity and CO_2 (*r* = 0.855) > Turbidity and WV (*r* = 0.747) > CO_2 and WV (*r* = 0.584) (Table 1). BOD (0.80) > N (0.77) > P (0.72) had the heavy +ve loadings on Factor 2, of which strongest +ve correlation between N and BOD (*r* = 0.549) has been observed under PPMCC analysis. Besides, moderate +ve correlation became evident between Phosphate and BOD (*r* = 0.413) > Phosphate and Nitrate (*r* = 0.331) (Table 1).TDS (0.86) > Hardness (0.85) > Alkalinity (0.78), all the 3 had the heavy loadings on Factor 3. All these parameters have a close relationship on the basis of the fact that dissolved solids have been found to contribute to the Hardness and Alkalinity regime of the water as evident from strong + ve correlation between TDS and Hardness (*r* = 0.761) > Alkalinity and Hardness (*r*=0.508) and moderate +ve correlationship between TDS and Alkalinity (*r*= 0.469) (Table 1). Though from the data Table (Table 3) width appeared having more loadings on Factor 4, yet depth (0.69) is also taken to be included under this Factor owing to its closeness to value ≥ 0.70. This contention of inclusion of depth under Factor 4 gains ground as strong + ve correlation has been observed between depth and width (*r* = 0.546) *vide* PPMCC analysis (Table 1).Water temperature (-0.88) > air temperature (- 0.77) were the 2 parameters having - ve loadings on Factor 5, thereby indicating their exclusive independency from other Factor components on one hand, but dependency amongst themselves on the other. The latter fact is potentially supported by the fact that water temperature and air temperature expressed strong + ve (*r* = 0.733) *vide* PPMCC analysis (Table 1).

Table 1. Pearson Product Moment Coefficient of Correlation computed between different Physico – chemical Water Quality variables for East

#	Water quality	D	W	AT	WT	WV	DO	CO_2	pH	Hd.	Alk.	Turb.	BOD	N	P	TDS
1.	D	1														
2.	W	0.546**†	1													
3.	AT	0.369**	0.226**	1												
4.	WT	0.113	0.085	0.733**†	1											
5.	WV	0.011	-0.016	0.241**	-0.061	1										
6.	DO	-0.413**	-0.177**	-0.757**††	-0.507**††	-0.246**	1									
7.	CO_2	0.285**	0.038	0.699**†	0.311**	0.584**†	-0.810**††	1								
8.	pH	-0.163**	-0.043	-0.608**††	-0.423**	-0.216**	0.543**†	-0.489**	1							
9.	Hd.	-0.498**	-0.260**	-0.230**	-0.094	0.096	0.305**	-0.089	0.130*	1						
10.	Alk.	-0.298**	-0.024	0.231**	-0.002	-0.256**	0.327**	-0.259**	0.304**	0.508**†	1					
11.	Turb.	0.290**	0.067	0.643**†	0.259**	0.747**†	-0.668**††	0.855**†	-0.536**††	-0.086	-0.285**	1				
12.	BOD	0.132*	-0.254**	0.184**	0.389**	-0.240**	-0.309**	0.188**	-0.075	-0.075	0.234**	0.066	1			
13.	N	0.034	-0.262**	0.070	0.182**	-0.475**	-0.125*	-0.057	0.114	-0.049	0.254**	-0.183**	0.549**†	1		
14.	P	0.291**	-0.107	0.309**	0.177**	-0.142*	-0.337**	0.319**	0.106	-0.241**	0.022	0.192**	0.413**	0.331**	1	
15.	TDS	-0.563**††	-0.212**	-0.210**	-0.044	0.265**	0.233**	0.018	0.016	0.761**†	0.469**	0.012	-0.110	-0.166**	-0.321**	1

Table 2. Pearson Product Moment Coefficient of Correlation computed between different physico – chemical Water Quality variables for West

S. No.	Water quality	D	W	AT	WT	WV	DO	CO_2	pH	Hd.	Alk.	Turb.	BOD	N	P	TDS
1.	D	1														
2.	W	0.820**†	1													
3.	AT	0.340**	0.171*	1												
4.	WT	0.338**	0.407**	0.782**†	1											
5.	WV	0.270**	-0.117	0.469**	0.291**	1										
6.	DO	-0.486**	-0.336**	-0.732**††	-0.558**††	-0.634**††	1									
7.	CO_2	0.440**	0.236**	0.847**†	0.461**	0.700**†	-0.905**††	1								
8.	pH	-0.093	-0.113	-0.490**	-0.452**	-0.226**	0.212**	-0.414**	1							
9.	Hd.	-0.487**	-0.666**††	-0.152*	-0.257**	0.210**	0.187**	-0.180*	0.149*	1						
10.	Alk.	-0.517**††	-0.620**††	-0.264**	-0.253**	-0.030	0.265**	-0.349**	0.273**	0.736**†	1					
11.	Turb.	0.465**	0.244**	0.796**†	0.457**	0.770**†	-0.794**††	0.891**†	-0.490**	-0.168*	-0.296**	1				
12.	BOD	-0.357**	-0.427**	0.015	0.113	0.038	0.076	-0.063	-0.098	0.588**†	0.414**	-0.050	1			
13.	N	-0.072	-0.044	-0.377**	-0.204**	-0.194**	0.095	-0.347**	0.358**	0.364**	0.680**†	-0.303**	0.589**†	1		
14.	P	0.018	-0.108	-0.034	-0.121	0.224**	0.207**	-0.059	-0.060	0.126	-0.109	-0.048	-0.132	-0.182*	1	
15.	TDS	0.503**†	0.385**	0.365**	0.453**	0.314**	-0.581**††	0.432**	-0.058	0.087	0.254**	0.390**	0.456**	0.498**	-0.259**	1

Table 3. Results of Factor analysis of Water Quality Variables of Eastern Doon

S. No.	Water Quality	Factor loadings				
		Factor 1	Factor 2	Factor 3	Factor 4	Factor 5
1.	Depth	0.21	0.20	-0.49	0.69†	-0.06
2.	Width	-0.04	-0.27	-0.08	0.91†	-0.12
3.	Air Temperature	0.42	0.16	-0.14	0.22	-0.78†
4.	Water temperature	-0.03	0.22	0.06	0.08	-0.88†
5.	Water velocity	0.85†	-0.36	0.10	-0.07	0.04
6.	Dissolved oxygen	-0.55	-0.28	0.25	-0.18	0.58††
7.	Carbon dioxide	0.86†	0.18	-0.05	0.07	-0.37
8.	pH	-0.34	0.11	0.15	0.10	0.72†
9.	Hardness	0.02	-0.10	0.85†	-0.22	0.09
10.	Alkalinity	-0.26	0.33	0.79†	0.19	0.15
11.	Turbidity	0.90†	0.01	-0.06	0.07	-0.32
12.	BOD	-0.01	0.80†	0.05	-0.08	-0.22
13.	Nitrate	-0.28	0.77†	0.001	-0.12	-0.09
14.	Phosphate	0.24	0.72†	-0.22	0.08	0.003
15.	TDS	0.13	-0.23	0.86†	-0.23	0.009
Explained Variation		3.1	2.38	2.51	1.59	2.58
Total Proportion		0.21	0.16	0.17	0.10	0.17

Table 4. Results of Factor analysis of Water Quality Variables of Western Doon

S. No.	Water Quality	Factor loadings			
		Factor 1	Factor 2	Factor 3	Factor 4
1.	Depth	0.38	-0.82†	-0.05	-0.21
2.	Width	0.12	-0.96†	-0.003	0.03
3.	Air temperature	0.91†	-0.06	0.10	0.11
4.	Water temperature	0.67††	-0.27	-0.07	0.27
5.	Water velocity	0.83†	0.20	0.02	-0.34
6.	Dissolved oxygen	-0.86†	0.26	0.10	-0.13
7.	Carbon dioxide	0.94†	-0.14	0.09	0.05
8.	pH	0.10	0.12	0.20	0.53††
9.	Hardness	-0.01	0.74†	-0.43	-0.25
10.	Alkalinity	-0.18	0.62	-0.72†	-0.01
11.	Turbidity	0.92†	-0.13	0.08	-0.02
12.	BOD	0.07	0.48	-0.76†	0.08
13.	Nitrate	-0.28	0.01	-0.87†	-0.02
14.	Phosphate	0.003	0.14	0.29	-0.77†
15.	TDS	0.48	-0.34	-0.77†	0.02
Explained Variation		4.96	3.13	2.81	1.21
Total Proportion		0.33	0.21	0.19	0.08

Legends: † = highest loadings ≥ 0.70; loadings †† = the parameter not showing heavy loadings on any Factor but falling close to 0.70. D = Depth D, W = Width W, WV = Water Velocity WV, AT = Air Temperature, WT= Water Temperature, DO =Dissolved Oxygen, CO = Carbon dioxide, H D. = Hardness, ALK. = Alkalinity, Turb. = Turbidity, BOD = Biological Oxygen Demand, N = Nitrates, P = Phosphates and TDS = Total Dissolved Solids.

The pH has been the 3rd parameter which had heavy loadings (0.71) on Factor 5 but towards positiveness. - ve and + ve loadings on the same Factor speak of no relationship among themselves, also substantiated by the fact that there was a strong - ve PPMCC between pH and air temperature (Table 1). Like East, only 13 out of 15 water quality stand factorized but into 4 Factors (against 5 in East), identified on the basis of high + ve or - ve loadings $p \geq 0.70$ (Table 4). The total variance explained by the Factors is 81.00%.4 parameters *i.e*. CO_2 (0.94) > Turbidity (0.91) > AT (0.90) > WV (0.82) had the +ve loadings, whereas only 1 parameter *i.e*. DO (- 0.86) had the – ve loading on Factor 1. Thus, a total of 5 variables showed loadings on Factor 1 as against 3 (with only +ve loadings) on Factor 1 in the East, but the commonness in the Factorization related with Factor 1 in East and West is that WV, CO_2 and Turbidity all come under Factor 1 in both the regions, emphasizing upon their relationships as also observed through *r*values of PPMCC among them (Tables 1 and 2).*r* values of PPMCC of West also emphasize upon strong +ve correlation between Turbidity and CO_2 (*r* = 0.891) > Turbidity and AT (*r* = 0.796) > Turbidity and WV (*r* = 0.770).In East, DO which was not resolved under any Factor and AT which was resolved under Factor 1 of the West, indicate towards their more influence and importance. The relationship of DO in the East appeared more with WT than with CO_2 and more with the latter in the West (substantiated by strong –ve correlation between CO_2 and DO (*r* = - 0.905) (Table 2). This phenomenon establishes the fundamentals very well, that DO is influenced by WT and CO_2 both, but their relationships may differ in different habitats *e.g*., the water bodies of the East (under survey) have more forested and protected (shaded) regions than in the West, hence differences in WT regime and level of biochemical attributes.

Width (-0.96) and depth (-0.82) are the 2 parameters which had –ve loadings in the light of the 3rd component under Factor 2 *i.e*., hardness (0.73) which had the +ve loadings. This combination is altogether different from the East leading to their different correlations observed (strong +ve between depth and width, *r* =0.820), strong –ve between Hardness and width (*r* = - 0.666) and weak –ve between hardness and depth (*r* = -0.487). The only thing of importance emerges that in both East (under Factor 4) and West (under Factor 2) width and depth do influence each other as substantiated by their strong +ve correlation observed for both East and West (Tables 1 and 2). A total of 4 parameters constitute the combination of all –ve loadings under Factor 3 *viz*., Nitrate (-0.87) > TDS (-0.76) > BOD (-0.76) > Alkalinity (-0.72). These parameters appeared having different levels of concomitant influences in the East (*i.e*., BOD and Nitrate under Factor 2 and Alkalinity and TDS under Factor 3), that too having +ve loadings. Their –ve loadings highlighted in the West signify their more importance against the rest of the parameters, but like the East, the relationship of Nitrate and BOD is substantiated by their strong correlation (r = 0.589) between them (Table 2). Strong correlation between Nitrate and Alkalinity (*r* = 0.680) and moderate +ve between TDS and Nitrate (0.498) and TDS and BOD (*r* = 0.456) is substantiated by the result of PPMCC (Table 2). Only 1 - ve loading (- 0.76) identifies the heavy loading of Phosphate under Factor 4, leading to the assumption of its least contribution in affecting the other parameters.

From the observations on *r* values of PPMCC of 15 water quality variables, strong +ve and strong –ve correlation coefficients obtained have revealed 2 aspects, firstly all correlations reaffirm the earlier findings by various authors and secondly these correlations vary from river to river and region to region on the basis of quantum of anthropogenecity, geological and geographical features. Kolo (1996) reported that variation in water qualities could be attributed to or explained in terms of dominance of precipitation chemistry, bedrock chemistry or evaporation – crystallization process within the entire water body. For Doon valley, it has been fascinating to observe that Turbidity and CO_2 (*r* = 0.855 in East and 0.891 in West) were the strongest +ve correlation showing parameters, due to the fact that increase in turbidity values inhibits the photosynthetic activity of phytoplankton, phytobenthos and accelerates consumption of oxygen by organic matter, thus reducing the DO content. Due to an inverse relationship between DO and CO_2 (Hynes, 1970), the positive relationship between Turbidity and CO_2 is accounted which was also observed by Gosain (1994), Bhutiani and Khanna (2007) and Sharma *et al*., (2008a).

More interestingly, 8 other combinations showing strong +ve correlations *viz*., AT and CO_2 (*r* = 0.699 in East and 0.847 in West), Width and Depth (*r* = 0.546 in East and 0.820

in West), AT and Turbidity (r = 0.643 in East and 0.796 in West), AT and WT (r = 0.733 in East and 0.782 in West), WV and Turbidity (r = 0.747 in East and 0.770 in West), Alkalinity and Hardness (r = 0.508 in East and 0.736 in West), WV and CO_2 (r = 0.584 in East and 0.700 in West) and Nitrate and BOD (r = 0.549 in East and 0.589 in West) have been observed common to both East and West but with slightly higher in the West r values. From amongst the earlier observations, the above referred correlations, majorly agree with the authors (AT and CO_2 with Bhutiani and Khanna, (2007); Width and Depth with Bellamy (1992); AT and Turbidity with Sharma *et al*., (2008a); AT and WT with Sharma (*et al*., 2009); WV and Turbidity with Negi *et al*., (2008) and Sharma *et al*., (2009); Alkalinity and Hardness with Bhatt and Pathak (1992) and Bhutiani and Khanna (2007); WV and CO_2 with Sharma *et al*., (2008b); Nitrate and BOD with Prathumratna *et al*., (2008). The 3 new combinations of strong +ve correlations observed for Western Doon were Nitrate and Alkalinity (r = 0.680), BOD and Hardness (r = 0.588) and TDS and Depth (r = 0.503). It is worth mentioning about the +ve correlation obtained between TDS and Depth (r = 0.503) on account of the fact that the same parameters swing towards strong –ve correlation for the streams of East. This difference is explainable on account of the difference in Depth, where streams of Eastern Doon record more depth as compared to the West, mainly due to perreniality, holding more water and submerged vegetation in most parts (S_8, S_{12}). In the West, the streams are shallow for most part of the year and majorly without submerged vegetation. It is worth mentioning that the latter plays as important role in precipitation of the suspended solids and keeping away the blooming effect of algal periphytonic forms. Hence, the positive correlation between Depth and TDS can be explained in a manner that though streams maintain some depth but the settling effect of suspended particles is slower as compared to the conditions provided with the streams in the East. That, Depth and TDS or *vice versa*, are correlated significantly, as has been elaborated by Prathumratna *et al*., (2008) who concluded that diversions of discharge flow increase the amount of total dissolved solids by concentrating the existing pollutants. Phyllis *et al*., (2007) reported that the concentration and composition of TDS in natural water is determined by the geology of the drainage, atmospheric precipitation and the water level. Correlation between Nitrate and Alkalinity (r = 0.680) has also earlier been pointed out (Gupta *et al*., 2012). Trivedy and Goel (1984) contented that the decomposing activity leads to release of nutrient ions (like bicarbonate, sulphate, chloride and nitrates of calcium and magnesium) which by changing TDS affect alkalinity regimen.BOD and Hardness are correlated (Bhutiani and Khanna, 2007) indirectly on account of the fact that as total hardness is due to the presence of bicarbonate, sulphate, chlorides and nitrates of calcium and magnesium which are recorded high during monsoons causing low levels of DO which further leads towards increment in the BOD values.

As far as the strong –ve correlations obtained are concerned, as many as 7 combinations of parameters in the East (Table 1) whereas 9 in the West (Table 2) exhibited strong –ve correlations. The correlations obtained between DO and CO_2 (r = - 0.810 in East and -0.905 in West) was the strongest one for both East and West. Such –ve correlation between DO and CO_2 is expected fundamentally, as has also been observed by Badola and Singh (1981) and Gosain (1994). Hynes (1970) stated that oxygen and CO_2 are usually inversely related to one another because of the photosynthetic and respiratory activity of the biota. The strong –ve correlations between DO and Turbidity (r = - 0.668 in East and - 0.794 in West) and AT and DO (r = - 0.757 in East and - 0.732 in West) were the other 2 important correlations common in East and West. How DO and Turbidity are inversely correlated has been elaborated by Gosain (1994), Mishra and Joshi (2003), Bhutiani and Khanna (2007), Sharma *et al*., (2008a) who inferred that turbidity interferes the penetration of light and cause common effect upon the river and aquatic life. Positive correlation between AT and DO is, obviously, as indirect one, through the impact of AT on WT, the latter deciding the solubility coefficient of gases (Welch, 1952; Hynes, 1970) and also observed by various workers (Sharma *et al*., 2008a, b; Basu and Lokesh, 2012). The combinations like AT and pH (r = - 0.608), Depth and TDS (r = - 0.563) and Turbidity and pH (r = - 0.536) were the exclusive strong –ve correlations observed for the East, especially for the downstream sections of river Song and Suwsa, on account of the fact that these sections are these stretches get direct insulation from the sunlight as they are less shaded as compared to the forested tract and the sections are mostly pooly and marshy. Correlation between air temperature and pH was also observed by Rawi and Shihab (2005). A –ve correlation between depth and TDS is explained on the basis of the fact that both have a direct bearing upon each other. As width influences depth, a correlation between depth and TDS was obvious as was also observed by Mondal *et al*., (2010) who stated that during summer months, extreme reduction of depth resulted in increase in hardness (contributed by TDS deciding factors).

A negative correlation observed between turbidity and pH was also observed by Bhatt *et al*., (2012). This –ve correlation is well explained in terms of the amount of rainfall in an area as explained by Atobatele *et al*., (2008) who stated that the pH decrease with increase in rainfall. As compared to East, the strong –ve correlations *viz*., Width and Hardness (r = - 0.666), WV and DO (r = - 0.634), Width and Alkalinity (r = - 0.620), DO and TDS (r = - 0.581), Depth and Alkalinity (r = - 0.517), were exclusively characteristic for the West. Width and hardness are negatively correlated, mainly due to the correlation observed between depth and width of a river (Anhwange *et al*., 2012). Water velocity and DO exhibited –ve correlation which is similar to the observations made by Sharma *et al*., (2008) and Prathumratna *et al*., (2008).Negative correlation between DO and TDS is very well supported in the light of the observations made by Charkhabi and Sakizadeh (2006), Negi *et al*., (2008) and Anhwange *et al*., (2012).Prathumratna *et al*., (2008) also reported –ve correlation between TDS and mean water level, which is directly applicable towards the –ve correlation between depth and alkalinity as also observed in the present observations. As TDS values directly influence the amount of hardness, the correlation between depth and alkalinity is obvious. The negative correlations between depth and alkalinity are understood in the light of the correlation observed between depth and TDS and similar reason is applicable here, too, as also opined by Mondal *et al*., (2010) for depth and TDS. Factor analysis of water quality parameters has facilitated explaining the correlations between the observations in terms of underlying Factors which are not directly observable, to identify most of the indices observed in water quality monitoring and to assess water quality with combined Factors (Shuxia *et al*., 2003). The number of Factors (also called Principal Components) were defined according to the criterion that only those Factors which account for variance > 1 are included (Khan, 2011). The Factor analysis emphasizes upon the fact that it is rare for any one water quality variable alone to control occurrence of fish species in the streams of a particular region (Matthews *et al*., 1992).

In the present study, as many as 5 physical (Depth, Width, Air temperature, Water temperature and Water velocity) and 10 chemical (Dissolved oxygen, Carbon dioxide, pH, Hardness, Alkalinity, Turbidity, Biological Oxygen Demand, Nitrate, Phosphate, Total dissolved Solids) water quality variables were used for Factor analysis, not been attempted so far for Doon Valley streams. Stevenson *et al*., (1974) provided one of the earliest multivariate analyses of fish distribution in a large region and included only 4 water quality variables (DO, Chloride, Sulphate and Hardness). Similarly, there had been other studies (Matthews *et al*., 1992; Mazlum *et al*., 1999; Yu *et al*., 2003; Ahmed *et al*., 2005; Kuppusamy and Giridhar, 2006; Boyaciaglu, 2006; Chenini and Kheimiri, 2009; Alam *et al*., 2010; Tololupe, 2011; Khan, 2011; Yidana *et al*., 2012) which included 6 – 23 water quality parameters for observing the combination of variables under various Factors generated after computing data for Factor analysis. Singh *et al*., (2005) did water quality assessment and apportionment of pollution sources of Gomti river and Factor Analysis/Principal Component Analysis applied to data set for 11 parameters, grouped into 6-7 latent factors. Kumar and Singh (2010) used 12 parameters and Khan (2011) used 13 parameters for Factor Analysis studies. Very recently, Gupta *et al*., (2012) while assessing habitat quality with relation to fish assemblages in an impacted river of Ganges basin have attempted Factor Analysis, in terms of Principal Component Analysis method for about 15 variables. Of the total water quality variables, 8 variables have been such which have been factorized under any Factor in almost the same combination as observed by earlier Factor analysis studies *e.g*., DO and WT — Factor 5 East and Factor 1 West (Mazlum *et al*., 1999, Gupta *et al*., 2012), TDS and Alkalinity — Factor 3 East and West, both (Mazlum *et al*., 1999; Kumar and Singh, 2010), TDS, Hardness and Alkalinity — Factor 3 East (Matthews *et al*., 1992; Kumar and Singh, 2010, Gupta *et al*., 2012), BOD and Nitrate - Factor 2 East and Factor 3 West (Boyaciaglu, 2006), TDS and Nitrate - Factor 3 West (Ahmed *et al*., 2005). The pH had been a single Factor which either resolved under the last factor or did not resolve at all, but on the basis of loading value fell close to last Factor (pH and Temperature, in Factor 5 of East, Table 3 and Factor 4, West, Table 4, respectively). The earlier observations have also indicated about figuring of pH loadings individually (Mazlum *et al*., 1999; Kumar and Singh, 2010 and Tololupe, 2011) or in combination with temperature under the last (Chenini and Kheimiri, 2009) or second last Factor (Gupta *et al*., 2012) resolved in their Factor analysis observations. This signifies that pH has its own identity and can be on account of many other anions or cations (which affect pH directly or indirectly) not included in the present study. pH and temperature combination (Factor 5 East) can be explained on the basis of the fact that pH of water gets changed with time, due to the exposure to air, biological activity and temperature changes (Trivedy and Goel, 1984). Total 7 variables *viz*., depth, width, air temperature, water velocity, CO2, turbidity and phosphate have not been undertaken for Factor analysis by earlier studies. In the present study, CO2, turbidity and water velocity formed Factor 1 in the East; AT, WT, WV, DO, CO_2 and turbidity formed Factor 1 in the West; depth and width formed Factor 4 in the East and 2 in the West, whereas AT, WT and DO formed Factor 4 in East. As far as Phosphate is concerned, it was found associated with BOD and Nitrate under Factor 2 in East and Factor 4 in the West. The aforesaid combinations of variables were not observed in earlier studies.

CONCLUSION

The results of the present study highlight the interrelationships amongst various water quality parameters. For the very first time multivariate statistical analysis has been done upon the water quality variables on a comparative basis between Eastern and Western Doon Valley streams.

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