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Assessing environmental contamination of River Ganga using correlation and multivariate analysis

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ABSTRACT: The aim of this study was to assess the environmental impact of socio-cultural practices on the water quality of River Ganga at the foothills of the Garhwal Himalayas in Uttarakhand State, India. The physico-chemical parameters that contributed to the temporal variation and pollution in the river were identified in this study. Principal component analysis (PCA) and Cluster analysis (CA) were used in the identification of anthropogenic factors (industrial, urban sewage, agricultural, land use and mining activities) and natural factors (soil erosion, weathering). The results of this study show that total coliform, fecal coliform, nitrate, sodium, phosphate, sulphate, TDS (Total dissolved solids), temperature, BOD (Biochemical oxygen demand), calcium and chloride are parameters significantly contributing to pollution load.

Keywords: cluster analysis, Ganga River, principal component analysis, water quality.

INTRODUCTION

There are fourteen major river basins in India of which River Ganga, the most reverend river, has been declared the National river of India. The river is fed by the glaciers of the Himalayas primarily by the twenty mile long and three mile wide Gangotri glacier. It travels 200 km through the Himalayas, and reaches the pilgrimage towns of Haridwar and Rishikesh (Uttarakhand) in the Shiwalik Hills and begins to flow in a south-eastern direction through the plains of northern India. River Ganga and its water quality has a bearing on the faith of Hindu devotee, regional economy, economy of state and tourism sector of Uttarakhand. Since past few decades, due to population explosion and rapid industrialization, the beautiful river has been exploited beyond its carrying capacity. Various aspects related to water quality of the River Ganga have been studied by various researchers (Bhutiani and Khanna, 2007; Khanna *et al*., 2007; Khanna *et al*., 2012; Khanna and Bhutiani, 2003a, Khanna and Bhutiani, 2003b; Khanna and Bhutiani, 2004; Khanna *et al*., 2009; Khanna *et al*., 2013). Bhutiani *et al*.(2014) found the water quality of River Ganga to be of poor quality through use of indexes. Its sacredness has been endangered due to unregulated human activities such as sewage and industrial wastes disposal, dead bodies disposal, deforestation, excessive use of fertilizers and pesticides, bathing during Ardhkumbh and MahaKumbh, pilgrimage etc. However, municipal discharge contributes to the pollution of RiverGanges in the Haridwar and Rishikesh region due to high influx of tourists and related activities. Khanna *et al*. (2008) reported the adverse

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impact of tourism related activities on the river body. Domestic sewage plays a dominant role in polluting the river. Heavy influx of organic as well as inorganic wastes exert huge impact due to tourism. Haridwar and Rishikesh are two well-known international tourist places. The biggest gathering of Hindus is also held at Haridwar, after every twelve years. Lakhs of devotees take a dip in the holy river. The health of the river is linked with the development of Uttarakhand State and plays a very important role in enhancing the regional economy and improving human habitat. Human activities such as intensive agriculture, urbanization and industrialization contribute to river water deterioration (Cachada *et al*., 2012). This study was carried out from June (2010) to May (2012) in the Haridwar–Rishikesh region of Uttarakhand State of India. This study identified water quality parameters that could lead to contamination of River Ganges in Haridwar and Rishikesh region and identified the sources of pollution by using correlation analysis and principal component analysis/cluster analysis (PCA/CA) methods.

MATERIALS AND METHODS

The study area is located in Haridwar-Rishikesh region in Uttarakhand State of India between 29°58"N-29◦58"N and 78°18′51″E-78°10"E. The climate of this particular area belongs to typical subtropical monsoon climate: hot and humid in summers and cold and dry in winters, and has a strong potential for producing enormous quantities of biomass. The sampling locations were selected to cover maximum sites where the actual bathing and other tourist activities were being carried out. Water samples were collected from six sampling sites (Figure 1) from Trivenighat (Rishikesh) to Mayapurghat (Haridwar). Sampling sites included Trivenighat (Rishikesh), Pashulokbarrage (Rishikesh), Raiwala (Rishikesh), Saptarishi (Haridwar), Har-Ki-Pauri (Haridwar) and Mayapurghat (Haridwar). Thus, the duration of the sampling was two years from June (2010) to May (2012). Water quality parameters included temperature, turbidity, TDS, pH, dissolved oxygen, biochemical oxygen demand, chemical oxygen demand, calcium, magnesium, chloride, fluoride, sodium, potassium, nitrate, phosphate and sulphate.

Fig. 1. Location and Study Area map showing the sampling stations

Samples were collected in plastic containers previously washed with detergents and HNO_3 acid and later rinsed with sampled water several times. The samples were then filtered through Whatman filter paper No.1 and preserved at 5°C. All samples were determined according to the American Public Health Association Standard Method for Water and Wastewater Analysis (APHA, 1998). The pH of water was estimated by pH meter, while temperatures of the samples were measured at the point of collection using mercury in glass thermometer. Conductivity and TDS were measured by digital conductivity and TDS meter. A turbidimeter was used to determine the turbidity of the samples. DO was measured by the Winkler's Azide method. Sample was collected BOD bottle and fixed at site using $MnSO_4$ and KI. BOD was measured from the differences of initial and 5 day DO. COD was determined by titrimetric method after 2 hr open reflux. The acidity and dissolved carbon dioxide were measured by titrimetric method using standard 0.02 M NaOH. The Total and phenolphthalein alkalinity were measured by titrimetric method using phenolphthalein and methyl orange as indicators. Total Alkalinity was determined by titrimetric method using a standard solution of 0.01 M HCl and methyl orange as indicator. Total Hardness was measured by adding calcium and magnesium using EDTA (Ethylene – Di amine Tetra – Acetic Acid) as titrant with ammonium chloride and ammonium hydroxide buffer solution and Erichrome Black T as indicator. Calcium hardness was determined using EDTA method with murexide (ammonium purpate) as indicator. Chloride was determined by the argentometric method, in a neutral or slightly alkaline solution using potassium chromate as indicator by standard silver nitrate as the titrant. Nitrate was determined colorimetrically by UV/visible spectrophometer (Agilent, Cary 60 UV Vis) using brucine sulphate as a complexing agent. Phosphate was also determined calorimetrically based on a blue complex induced by the addition of stannous chloride. Sulphate was determined turbidimetrically with spectrophotometer using barium chloride as the precipitating agent. TS and TSS were determined gravimetrically and flouride was determined by the SPADNS Zirconium Lake Colorimetric method. The total solid (TS) present in 100 ml of sample water was calculated by evaporating the water sample at 103 to 105°C to dryness and keeping the beaker in drying oven, cooling it in desiccators and then weighing the beaker. The TS in mg/1 was the difference in weights of the beaker before filling with sample and after evaporation of sample. All analyses were carried out in triplicate and the mean of three readings was taken as the value. Statistical calculations were performed using the "Statistical Package Software; SPSS-11.5 and Minitab for Windows". Correlation and other multivariate statistical techniques (PCA and CA) were used to analyze water quality dataset obtained from River Ganges.

RESULTS AND DISCUSSION

Baseline Water Quality

Table 1 summarizes the descriptive statistics of the river water quality including mean, median, minimum, maximum, standard deviation and standard error. All the physico-chemical parameters were found to be within permissible water quality limits. However, parameters: Total Coliform and Fecal Coliform were found to exceed permissible standard limits.

Correlation Coefficient. Correlation coefficient is commonly used to measure and establish the relationship between two variables. It is a simplified statistical tool to show the degree of dependency of one variable to the other (Belkhiri *et al*., 2010). From the matrix plot, strong (r=0.8 to 1.0), moderate (r=0.6 to 0.8) and low (r=0.5 to 0.6) correlation between the selected variables was determined (Table 2). correlation analysis between Total coliform

Table 1. Baseline water quality parameters in the study area

Parameters	Mean	Median	Minimum	Maximum	SD	SE
Temperature (^{O}C)	18.7	18.75	14.12	22.62	2.69	0.55
Turbidity (Siemens/cm)	4.85	5.25	2.87	6	0.84	0.17
TDS (mg/l)	55.62	52.65	34.14	89.41	17.4	3.55
pH	7.61	7.58	7.47	7.78	0.09	0.01
DO (mg/l)	9.71	9.68	8.76	10.6	0.49	0.1
BOD (mg/l)	1.9	1.91	1.41	2.44	0.25	0.05
COD (mg/l)	6.05	6	5.02	8	0.66	0.135
Ca (mg/l)	25.34	25.43	18.02	32.96	4.53	0.92
Mg (mg/l)	6.48	5.54	3.6	13.03	3.09	0.63
Cl (mg/l)	24.43	25.87	13.8	35.52	6.19	1.26
F (mg/l)	0.14	0.14	0.12	0.23	0.03	0
Na (mg/l)	10.84	9.31.	6.94	17.09	3.75	0.76
K (mg/l)	2.72	2.72	1.75	3.55	0.58	0.12
NO_3 (mg/l)	0.18	0.18	0.13	0.22	0.02	0
PO_4 (mg/l)	0.06	0.06	0.04	0.09	0.01	0
SO_4 (mg/l)	21.07	20.53	18.31	24.29	2.03	0.41
Total Coliform	2606.3	2742.1	1981.4	3138	344	70.2
Fecal Coliform	4236	4701	2269	5548	1126	230

Table 2. Matrix showing coefficient of correlation between parameters

	Temp	Turbidity	TDS	pH	DO	BOD	COD	Ca	Mg	Cl	Fl	Na	K	Ni	PO_4	SO_4
Temperature																
Turbidity	0.63															
TDS	0.17	0.4														
Ph	0.14	0.13	0.37													
DO	-0.62	-0.42	-0.5	-0.6												
BOD	0.85	0.5	0.13	0.35	-0.8											
COD	0.29	0.56	0.2	-0.1	-0	0.1										
Calcium	0.78	0.61	0.46	0.56	-0.8	0.76	0.25									
Magnesium	-0.39	0.38	0.31	-0.1	0.17	-0.38	0.28	-0.3								
Chloride	0.79	0.6	0.61	0.31	-0.8	0.75	0.31	0.85	-0.2							
Fluoride	-0.06	0.3	0.35	0.32	-0.2	-0.14	-0.06	0.27	0.33	0.1						
Sodium	0.27	0.43	0.75	0.57	-0.7	0.42	0.09	0.62	0.08	0.6	0.4					
Potassium	-0.49	0.13	0.58	0.23	0.09	-0.45	0.15	-0.1	0.67	-.1	0.5	0.5				
Nitrate	0.16	0.43	0.59	0.37	-0.4	0.25	0.17	0.48	0.15	0.5	0.5	0.8	0.6			
Phosphate	-0.03	0.61	0.65	0.12	-0.2	-0.08	0.34	0.25	0.68	0.3	0.6	0.6	0.8	0.7		
Sulphate	0.24	0.54	0.77	0.48	-0.7	0.34	0.16	0.64	0.28	0.6	0.5	0.9	0.5	0.8	0.79	
TC	-0.08	0.26	0.44	0.2	0.12	-0.04	0.26	0.29	0.2	0.2	0.5	0.7	0.7	0.9	0.72	
FC	0.09	0.49	0.63	0.32	-0.2	0.08	0.45	0.43	0.3	0.5	0.5	0.7	0.7	0.8	0.79	0.88

and nitrate (0.86), Total coliform and phosphate (0.72), fecal coliform and nitrate (0.81), fecal coliform and phosphate (0.79), Fecal coliform and Sulphate (0.75) suggested the luxurious growth of microbes due to heavy influx of organic matter. Sodium and nutrients such as nitrate (0.81), sulphate (0.88) and phosphate (0.622) showed high degree of correlation. Potassium also showed high degree of correlation with phosphate (0.76), indicating that pollution is caused by agricultural runoff. TDS showed good correlation with sodium (0.75) and sulphate (0.77). Temperature showed strong correlation with BOD (0.85), calcium (0.78) and chloride (0.79). BOD showed strong correlation with calcium (0.76) and chloride (0.75). Calcium and Chloride (0.85) showed a very high degree of correlation with domestic sewage, as well as land use activities. Parameters such as temperature, BOD, calcium, chloride and turbidity showed high inter dependency among each other and were associated with pollution caused by organic pollutants e.g negative correlations were observed among DO, BOD and COD. The results of correlation indicated that TDS showed moderate relation with calcium (0.46), chloride (0.61), potassium (0.58), nitrate (0.59) and phosphate (0.65). While turbidity was found to be moderately associated with BOD (0.50), COD (0.56), calcium (0.61), chloride (0.60), sodium (0.43), nitrate (0.43), phosphate (0.61) and sulphate (0.54). The pH showed moderate correlation with calcium (0.56) and sodium (0.57), while moderate correlations were observed between calcium and sulphate (0.64), calcium and nitrate (0.48), calcium and sodium (0.62), magnesium and potassium (0.67), magnesium and phosphate (0.68), chloride and sodium (0.61), chloride and sulphate (0.60), sodium and potassium (0.52) and potassium and nitrate (0.55). Table 2 shows the results of correlation between parameters. All these associations suggested that the surface chemistry of the river is mainly controlled by temperature, TDS, Na, chloride and nutrients. The high Na and Cl contents detected in certain samples suggests the dissolution of chloride salts. Research shows that dissolution of halite in water releases equal concentrations of Na and Cl into the solution (Belkhiri *et al*., 2010).

Principal Component Analysis/Factor Anaysis (PCA/FA) was applied to the data set to identify the principal factors of pollution. Mathematically, PCA normally the following five major steps: i) Coding of the variables $X_1, X_2, \ldots\ldots X_n$ (which are the 16 physico-chemical parameters in the present study) and standardization of the measurements to ensure that all have equal weights in analysis, ii) The calculation the covariance matrix C, iii) Calculation of the Eigen values and corresponding Eigen vectors of the covariance matrix, iv) Discarding any component that account for small proportions of variation in dataset, v) Choosing components and forming a feature vector. FA attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable (Yu et al., 2003). It helps in identifying the possible factors/sources that influence water quality (Panda et al., 2006; Bu et al., 2009). The main purpose of FA is to reduce the contribution of less significant variables in order to simplify more of the data structure coming from PCA. This can be achieved by rotating the axis defined by PCA, according to well-established rules and constructing new variables also called varifactors (Shrestha and Kazama, 2008). Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable. It reduces quality space from a larger number of variables to a smaller number of factors. The variables with similar characteristics were grouped and some redundant information was taken off. Some new factors were produced which might be the linear combination of the original variables and had the capability of explaining the observed variance in the larger number of variables. Factor analysis takes data contained in a correlation matrix and rearranges them in a manner that better explains the structure of the underlying system that produced the data. However, before applying PCA/FA analysis, the Kaiser Meyer Olkin test (KMO) and Bartlett's test were applied on the data set. The KMO result was 0.687 and the Bartlett sphercity test was significant (0.0001, $P<0.01$), showing that PCA could be considered appropriate and useful in providing significant reduction in data dimensionality (Hutcheson *et al*., 1999). An Eigen value gives a measure of significance for any factor. Therefore, Eigen values of 1.0 or greater are considered significant (Kim and Mueller, 1978). Kaiser's varimax rotation scheme was employed and factor loadings were classified as 'strong', 'moderate' and 'weak', corresponding to absolute loading values of >0.75, 0.75–0.50 and 0.50–0.30, respectively (Kim and Mueller, 1978). PCA revealed that the first four factors explained approximately 85.40% of the total variance. Evidently, the first factor was more correlated with the variables than the other factor. Four varifactors (VFs) shown in Table 3 were obtained through the FA performed on the PCs. Table 3 shows that the four varimax rotated factors accounted for more than 85% of the total variance and hence could explain temporal variation in the hydrochemistry.

Table 3. Varifactors identified through PCA

Variables	VF1	VF2	VF3	VF4	Communality
Temperature	-0.084	0.922	0.138	-0.238	0.932
Turbidity	0.210	0.636	-0.521	-0.422	0.898
TDS	0.561	0.356	-0.459	0.155	0.676
pH	0.303	0.415	-0.108	0.612	0.650
DO	-0.185	-0.850	0.102	-0.374	0.908
BOD	-0.023	0.916	0.198	0.019	0.880
COD	0.207	0.237	-0.216	-0.773	0.743
Calcium	0.318	0.898	0.002	0.079	0.913
Magnesium	0.139	-0.294	-0.890	-0.193	0.936
Chloride	0.309	0.874	-0.005	-0.099	0.870
Fluoride	0.470	0.014	-0.467	0.297	0.528
Sodium	0.761	0.467	-0.181	0.265	0.900
Potassium	0.695	-0.366	-0.543	0.092	0.921
Nitrate	0.892	0.262	-0.094	0.040	0.875
Phosphate	0.694	0.057	-0.653	-0.169	0.939
Sulphate	0.736	0.454	-0.373	0.179	0.919
Total Coliform	0.974	-0.035	-0.026	-0.110	0.962
Fecal Coliform	0.900	0.178	-0.211	-0.206	0.929

Factor 1 explained 45.40% of the total variance and had strong positive loadings for total coliform and Feacal coliform. This factor keened towards a negative influence on surface water quality as a result of domestic waste. Hence, this factor represented organic contamination. In addition, this factor had moderate loadings for TDS, sodium, nitrate, potassium and phosphate, indicating that pollution sources included agricultural runoff from a nearby region. This factor also represents erosion from upland areas during rainfall as TDS had high loading for this very factor (Shrestha and Kazama, 2007). Factor 2 had strong positive loading on biochemical oxygen demand (BOD5) and Temperature and strong negative loading on Dissolved oxygen. The amount of variation explained by this factor was 24.20% of the total variation. This factor has moderate to high loading for Turbidity, Calcium and chloride. These are the indicators of pollution caused by the land activities in the river basin and the influx of domestic discharge. Turbidity of the water could be a result of suspended clay, silt and fine divided colloidal matter (Juahir et al., 2010).This verified that anthropogenic activities were influencing the water body. This factor was as a biochemical pollutant indicator. Factor 3 had high loading for COD and slightly negative loading for pH, thus indicates slight pollution from industrial sewage. The industrial activities were incident from nearby region and were likely to be the source of Factor 3. Thus this factor represented the organic, as well inorganic contamination. Factor 4 had a high positive loading for pH and high negative loading for DO. This factor was labeled as water quality indicator and explained 5.80% of the total variation. Additional factors provide marginally less explanatory capability and were not examined further. Magnesium, Fluoride and COD were considered as non principal on the basis of first two factors as it accounted for 69.60% of the total variance. The Loading plot given in Figure 2 shows the position of Total coliform, Fecal coliform, Nitrate, Sodium, Phosphate, Sulphate and TDS towards the right most corner along VF-1 (Factor 1) axis that represent their maximum contribution and their position near to zero along PC-2 axis, which shows almost no contribution at all. Temperature, BOD, Calcium and Chloride were observed to be towards the left most corner of the plot indicating no contribution of these parameters to the VF-1, while maximum contribution along the VF2 axis is shown. 64% variance is seen along PC-1 axis where TDS lies at the right most position. The remaining parameters such as pH, COD and Magnesium were found to be centralized showing negligible contribution towards either factor.

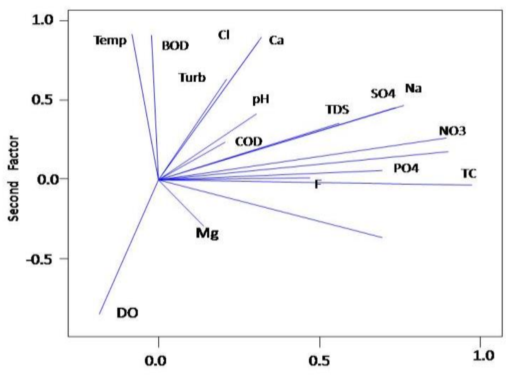

Fig. 2. Temperature-FC loading plot

Cluster Analysis. On the basis of Cluster analysis, dendrogram grouping of 16 parameters into two main clusters was obtained (Fig. 3). First, the cluster group showed close association between Total coliform and Fecal coliform. This group accompanied with the second group having Sodium and sulphate to a better degree. The TC and FC were found to be linked with nutrients such as Nitrate and Sulphate, and were also supported by the correlation coefficient among these variables. Another group showing high degree of association was Calcium and Chloride, as well as BOD and Temperature. This group was observed to be the second most significant anthropogenic factor polluting the river's water. Moreover, high value of correlation was noticed among BOD and Temperature, as well as Calcium and Chloride. The association between these parameters and the values of correlation coefficients indicated anthropogenic activities such as Domestic discharge and land activities in the river basin. Few more parameters were observed to be in close association with each other e.g. sodium and nitrate, sodium and phosphate and temperature and calcium. A high degree of correlation among temperature, Ca and Cl was observed. Beside, Sodium and nutrients also showed high degree of correlation. Thus, the findings are in excellent agreement with the result of correlation and cluster analysis. TDS was found to be closely associated with various parameters such as Sodium, Potassium and Magnesium as shown by the Dendrogram in Figure 3. Further, Sodium also showed association with Nutrients, while nutrients were closely linked with TC and FC. However, a group of parameters such as TDS, Sodium, K nutrients and TCFC was formed indicating that the primary most significant factor polluting the river water was due to anthropogenic activities such as agricultural runoff, industrial sewage and mineral weathering. The enrichment of Na, K and Cl ions in surface water could be attributed to the interaction of water with rocks and secondly, the association of TDS with higher concentration of Na and K ions.

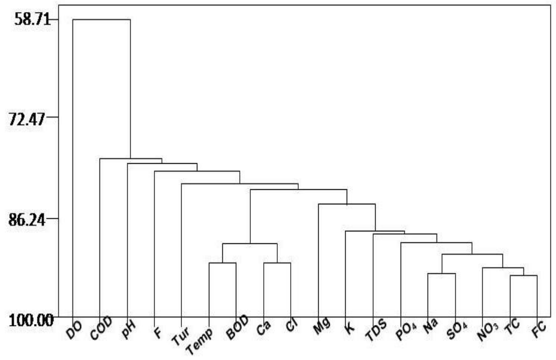

Fig. 3. Dendogram showing clustering of parameters

CONCLUSIONS

In this study, four most significant factors were identified as causal agent of temporal variation at all the study's sites. The first two factors indicated anthropogenic influence on the overall river water quality due to domestic sewage, agricultural runoff and slight land use activities. The third and fourth factors represented anthropogenic impacts such as industrial and mining activities. The results showed that physico-chemical parameters namely total coliform, feacal coliform, nitrate, sodium, phosphate, sulphate and TDS, temperature, BOD, calcium and chloride were principal factors contributing to pollution load. Similar results were reported in another study of River Cauvery in Karnataka, India where the main factors included BOD, COD, TC, FC, Conductivity, TDS and chlorides (Sudevi and Lokesh, 2012). The overall analysis supported the fact that the main contributors towards the temporal variation among the parameters in river water were Domestic and other discharges. A similar finding was noted in a study in Sri Lanka, which concluded that the water quality of Kelani River significantly depends on the different land use characteristics (Athukorala *et al*., 2013). This could be attributed to increased tourist activities leading to heavy organic and inorganic influx into the river's water in the form of Domestic sewage. Cluster analysis was in line with the results of Factor analysis. Non principal parameters: Magnesium, fluoride and COD were identified as non principal parameters on the basis of factor analysis and cluster analysis, as these parameters did not explain the temporal variation in this study. The outcome showed that there was a potential for improving the efficiency and economy of the monitoring network in this particular river by reducing the number of monitoring parameters.

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