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Assessment of Significant Sources Influencing the Variation of Water Quality of the River Damodar through Factor Analysis

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Abstract: In the present study, a large environmental data matrix, obtained during one year monitoring programme of 18 parameters at 16 different sites, subjected to factor analysis (FA) to study the geochemical status and to discriminate the different pollution sources of the river Damodar. Various physicochemical parameters like pH, electrical conductivity (EC), total dissolved solid (TDS), ammonia (NH_4^+), chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), iron (Fe), cadmium (Cd), manganese (Mn) and lead (Pb) were determined following the standard methods of APHA (1998). The average concentrations (μg/l) of the heavy metals in the water are Fe (598.4) > Pb (2.813) > Mn (1.369) > Cd (0.538). Factor analysis reveals four factors like industrial effluents, geogenic sources, agricultural activities and natural factors controlling the variability in waters of the river Damodar. The study of cluster analysis classified monitoring sites (16) into three clusters i.e., relatively less polluted, moderately polluted and highly polluted area. These results indicate that heavy metal pollution and toxicity might pose serious risks to the health of communities using these surface waters for domestic, commercial and socio-cultural purposes. It is, therefore, recommended that more strict methods of waste effluent management should be adopted to reduce further inputs into the study area.

Key words: Water quality, heavy metals, factor analysis, cluster analysis, Damodar river.

Introduction

The waters of the river that flows through variable topography and geology during its course are most vulnerable to pollution due to the easy accessibility to river waters of waste disposal. Anthropogenic influences degrade surface waters and impair their use for drinking, industrial, agricultural or other purposes. Natural water quality is controlled by complex processes such as precipitation rate, weathering processes, urban, industrial and agricultural activities and exploitation of water resources etc. Surface water quality in a given region is determined by both natural and anthropogenic influences (Jarvie et al., 1998; Mokaya et al., 2004; Melina et al., 2005; Singh et al., 2005a; Ouyang et al., 2006). The mining and its related operations are the most significant anthropogenic sources of heavy metals that severely degrade water quality, and can kill aquatic life and make water virtually unusable (Tiwary and Dhar, 1994; Conesa et al., 2007; Vanderlinden et al., 2006; Vanek et al., 2005).

Various industrial as well as intensive agricultural activities have resulted in a variety of heavy metals being released into the environment with concentrations above the normal standards of the natural background (De Groot et al., 1976; Dryssen and Wedborg, 1980). Rapid industrialization and consequent urbanization influenced the chemistry of surface water (Al-Kharabsheh, 1999; Karn and Harada, 2001; Wang, 2001; Kelsey et al., 2004)

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and the physicochemical, biological quality of waters (Goda, 1991; Young and Thackston, 1999; Izonfuo and Bariweni, 2001) which ultimately lead to several problems of water quality. Heavy metal toxicity due to various types of anthropogenic activities disrupts natural ecosystems and due to their toxicity, persistence and bioaccumulation, affects the food chain, leading to health problems in animals and plants also.

Factor analysis (FA) technique is a multivariate statistical approach and is very useful in the analysis of data corresponding to large number of variables. In the techniques of factor analysis, the initial set of variables is substituted by a smaller group of factors, which preserve as much information contained in the original variables as possible (Fachel, 1976). Factor analysis identifies and quantifies basic standards of variation in the large data set, and allows the construction of an index that accounts for the variability with a smaller, simpler number of vectors than those obtained using the original data (Lohani and Mustapha, 1982). The factor analysis technique involves preparing the correlations matrix between analysed variables, the extraction of factors and a possible rotation, seeking a final solution with simpler factors that are easier to interpret. It also enables us to explain the relationships between numerous important variables and a smaller set of independent variables and widely applied to investigate environmental phenomena in recent years in order to obtain appreciable data reduction for analysis and decision (Chapman, 1992; Kucuksezgin, 1996; Chiacchio et al., 1997; Vega et al., 1998; Morales et al., 1999; Helena et al., 2000). The factor analysis is applied in this study to identify sources of the elements in the river and to describe water quality.

Materials and Methods

In order to evaluate the quality of river water in study area, water samples were collected from sixteen locations of Damodar river (from Asansol to Burdwan) along with its tributary the river Barakar near Barakar township region to evaluate the heavy metal contamination during various seasons (summer, monsoon and winter of 2008). Criteria for selection of sampling station were based on the locations of industrial units and land use pattern to quantify heavy metal concentration along with it various water quality parameters. Four sites were selected along the Barakar river and twelve sites were located along its main river. The river water samples were taken from 10 to 15 cm below the water surface using acid washed plastic container to avoid unpredictable changes in characteristic as per standard procedures (APHA, 1998). The samples for dissolved trace metals were acidified with high-purity HNO_3 and then stored at approximately 4^oC before analysis.

Field and Laboratory Methods

The pH and electrical conductivity (EC) were measured using digital conductivity meters immediately after sampling. Water samples were filtered through Whatman no. 42 filters immediately after collection and preserved with 6N of HNO_3 for further analysis. The various physicochemical attributes of water samples such as pH, electrical conductivity (EC), total dissolved solids (TDS), ammonia (NH_4^+), chloride (Cl^-), nitrate (NO_3^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}) and heavy metals like cadmium (Cd), iron (Fe), manganese (Mn) and lead (Pb) were analyzed following the standard procedure of APHA (1998). Concentrations of heavy metals in water samples were determined with an atomic absorption spectrophotometer (GBC-Avanta) with a specific lamp for particular metal. Average values of three replicates were taken for each determination.

Statistical Analysis

The experimental data were treated statistically and the descriptive statistical analysis (mean, standard deviation and coefficient of variance) of the data obtained from the study were calculated. The Pearson correlation studies, and factor analysis (FA) were carried out on the various water parameters along with metals. Correlations study was performed for different water parameters including metals for analyzing the interrelations between them. Statistical methods of analysing hydrochemical data, such as factor analysis, can be a useful tool in identifying the likely factors that cause the variations in hydrochemical composition. Cluster analysis (CA) may classify monitoring sites according to similar objects and is applied in this study to identify the sites with similar characteristics.

Results and Discussion

Water Quality of the River

The analytical results of the chemical analysis and the statistical parameters such as minimum, maximum, mean, standard deviation and coefficient of variance of the Damodar river water are presented in Table 1. Correlation coefficient calculation of all water quality parameters is represented in Table 2. Factor loading matrix, eigenvalues and variances of factor analysis (FA)

Table 1: Summary statistics for all measurements on the Damodar river system

Parameters	*Minimum*	*Maximum*	*Average*	*Standard deviation*	*Coefficient of variance*
pH	7.00	8.95	7.96	0.40	5.00
EC	110	710	302.8	133.9	44.22
TDS	76.4	481.6	193.4	87.37	45.18
TH	56.0	280	119.5	37.44	31.32
SO_4^{2-}	5.78	80.35	21.71	12.95	59.65
PO_4^{3-}	0.00	1.60	0.14	0.16	111.8
NH_4^+	0.00	2.12	0.26	0.24	92.47
NO_3^-	0.00	3.85	0.62	0.58	93.20
Cl^-	1.24	77.69	13.46	10.00	74.34
Na^+	4.05	46.69	14.19	5.22	36.77
K^+	1.04	22.28	5.42	3.19	58.89
Pb	0.00	99.54	2.813	7.76	275.80
Cd	0.00	3.875	0.538	0.77	142.67
Fe	11.00	3716	598.4	639.0	106.89
Mn	0.00	43.57	1.369	3.30	241.05

is represented in Table 3. The results revealed that, in most of the river, water was neutral to alkaline in nature. The pH values did not show remarkable differences neither between sampling sites nor between sampling periods and the mean values for each site ranged 7.00–8.6. High level of pH in the river water may result in the reduction of heavy metal toxicity (Aktar et al., 2010). The increase of pH in the non-industrial downstream area could be due to agricultural run-off that is usually alkaline in nature. Electrical conductivity (EC), which is a measurement of the ionic strength of solution, varies between 110 and 710 µS/cm. TDS is an expression for the combined content of all inorganic and organic substances and it varies between 76.4 and 481.6 mg/l. Higher concentration of TDS (349.76 mg/l) was observed in the river water near the site Chinakuri and this might be due to high amount of dissolved ions. Higher values of TDS were observed in river samples where industrial effluents and coal mine effluents are discharged into the river directly. The EC and TDS have high standard deviation compared to other parameters and suggest that water chemistry is not homogenous in the study area and regulated by distinguished processes. Various large and small industries are concentrated in the left bank of the river. The effluents from these industries are directed into the river course which increase the concentration of TDS in the river water bodies. Results of the total dissolved solids (TDS) revealed that there was a considerable amount of dissolved ions in all the sampling locations.

The hardness of natural waters depends mainly on the presence of dissolved calcium and magnesium salts; in the study it ranges from 56 to 280 mg/l. PO_4^{3-} is present in natural waters as soluble phosphates and organic phosphates. Phosphate concentration (1.60 mg/l) is maximum at the station Gobindapur Charmana due to the non-point agricultural sources. The maximum nitrate concentration (2.80 mg/l) was observed in the Damodar river at station Madanpur due to the non-point agricultural sources. The peak concentration was probably partially a result of rainfall, washing out nitrates from fertilizers. Similar pattern was also observed for ammonium and phosphates. Ammonia in elevated concentration is harmful to aquatic fishes and other life. The toxicity of ammonia increases with the increasing pH because at higher pH most of the ammonia remains in the gaseous form. At low pH condition due to conversion of ammonia into ammonium ions, which are much less toxic than the gaseous form, decreases its toxicity. The ammonia concentration ranges from 0.0 to 2.12 mg/l. The mean concentration (mg/l) of chloride, sulphte, sodium and potassium is 13.46, 21.19, 14.19 and 5.41 respectively.

The mean concentrations (µg/l) of the examined heavy metals (Cd, Pb, Mn and Fe) show little variations between different sampling sites (Table 1), suggesting mainly influence from point sources. In general, dissolved metal concentrations at all sampling sites were low. Lead (Pb) is a toxic heavy metal which generally occurs at low concentrations in natural waters (Coale and Flegal, 1989). The elemental concentrations in river waters are different during the three investigation periods; the concentrations are higher during the post-monsoon season. In natural water the decrease of metal concentrations with increase in pH may result from an increased adsorption when pH increases according to the surface complexation theory

Table 2: Correlation coefficient matrix of physicochemical variables in the Damodar river water

Variables	*pH*	*EC*	*TDS*	*TH*	*Na^+*	*K^+*	*NH_4^+*	*SO_4^{2-}*	*NO_3^-*	*Cl^-*	*PO_4^{3-}*	*Mn*	*Fe*	*Cd*	*Pb*
pH	-														
EC	-0.415	-													
TDS	-0.427	**0.978**	-												
TH	-0.135	**0.628**	**0.633**	-											
Na^+	0.342	-0.068	-0.009	0.158	-										
K^+	0.353	-0.086	-0.093	0.181	0.328	-									
NH_4^+	0.090	0.104	0.046	-0.239	0.170	0.170	-								
SO_4^{2-}	-0.217	**0.752**	**0.701**	0.200	-0.353	-0.162	0.253	-							
NO_3^-	0.024	0.112	0.072	0.154	-0.179	-0.044	-0.162	0.141	-						
Cl^-	-0.186	**0.530**	0.455	0.266	-0.238	-0.113	0.075	**0.639**	0.408	-					
PO_4^{3-}	-0.355	-0.185	-0.176	-0.250	0.232	0.126	0.376	-0.226	-0.293	-0.066	-				
Mn	0.253	0.087	0.104	0.494	0.347	**0.721**	-0.133	-0.194	0.375	0.123	-0.002	-			
Fe	-0.307	**0.673**	**0.540**	0.164	-0.192	-0.094	0.389	**0.717**	0.049	**0.655**	-0.007	-0.247	-		
Cd	-0.249	**0.861**	**0.809**	**0.498**	-0.286	0.045	0.135	**0.902**	0.105	**0.639**	-0.327	0.011	**0.748**	-	
Pb	-0.212	**0.610**	**0.645**	0.228	-0.344	-0.099	0.000	**0.717**	0.046	**0.626**	-0.279	-0.088	0.464	**0.732**	-

Values in bold are different from 0 with a significance level alpha = 0.05.

Table 3: Factor loading matrix, eigenvalues and variances

Parameters	*F1*	*F2*	*F3*	*F4*
pH	-0.384	0.378	-0.173	***0.637***
EC	***0.932***	0.148	0.133	-0.206
TDS	***0.886***	0.175	0.115	-0.296
TH	0.479	***0.581***	-0.043	-0.343
Na	-0.277	***0.405***	0.373	-0.008
K	-0.135	***0.611***	0.320	0.243
NH	0.099	-0.167	***0.593***	0.424
SO_4	***0.886***	-0.180	0.006	0.274
NO_3	0.179	0.251	***-0.316***	0.076
Cl	**0.713**	0.030	-0.016	0.212
PO_4	-0.258	-0.212	***0.846***	-0.222
Mn	-0.032	***0.949***	0.111	-0.012
Fe	***0.744***	-0.222	0.255	0.225
Cd	***0.958***	0.076	0.004	0.151
Pb	***0.735***	-0.070	-0.125	0.101
Eigenvalue	**5.539**	2.246	1.566	1.151
Variability (%)	**36.93**	14.97	10.44	7.674
Cumulative %	**36.93**	51.90	62.34	70.01

Values in italics with bold set indicates significant loading.

(Schindler and Stumm, 1987) or simply based on ion solubility. Cadmium, a non-essential heavy metal, ranges from 0.00 to 3.875 µg/l. Iron and manganese was detected in most of the samples (µg/l) in the range of 11.0-3716 and 0.00-43.57. The presence of little higher value of heavy metal in water is indication of pollution in the river. Acid mine drainage is the source of sulphate and metal ions to water environment of the river Damodar. The study reveals that the metal concentration is higher in post-monsoon season; this might be due to the dilution effect during rainy season and the formation of metal chelates during post-monsoon (winter) in particular.

Correlation Matrix

The compositional relations among dissolved species in natural water can reveal the origin of solutes and the process that generated the observed water compositions. Correlation is widely used in statistical analysis and the purpose of this analysis is to measure the intensity of association between two variables. Such association between variables likely lead to reasoning about causal relationship between the variables. The correlation analysis is a preliminary descriptive technique also used to estimate the degree of association among the variables involved. Statistical analyses indicate positive correlation between some pairs of parameters shown in Table 2.

Good correlation was observed between SO_4^{2+} and EC (0.752), TH and EC (0.628), Cl and EC (0.530), Cl^- and SO_4^{2+} (0.639), SO_4^{2+} and TDS (0.701), and Cl and TDS (0.455) indicating that all of them have the same origin. EC and TDS (0.978) showed a good correlation because conductivity increases as the concentration of all dissolved constituents/ions increases. Almost all analyzed metals in this study showed good correlation with conductivity because conductivity increases with dissolution of metals through ion exchange or oxidation-reduction reaction. Positive correlations exist between elemental pairs Cd and Fe (0.748), Pb and Fe (0.464), and Cd and Pb (0.732) which suggest a common source and these may be from anthropogenic sources like mining and industrial activities along its course.

Factor Analysis (FA)

Factor analysis of the study (Table 3) concluded four factors (eigen value >1) considering 70.01% of total variance in data set. The results of factor analysis performed on physicochemical parameters and heavy metals suggested four factors controlling their variability in waters of the river Damodar. The varimax rotated factor analyses were calculated using eigenvalues greater than 1.0 applied to the study. According to Liu et al. (2003), factor loading is classified as 'strong', 'moderate' and 'weak', corresponding to absolute loading values of >0.75, 0.75-0.50 and 0.50-0.30, respectively. The ordination and scree plot of the physicochemical parameters are represented in Figures 1 and 2

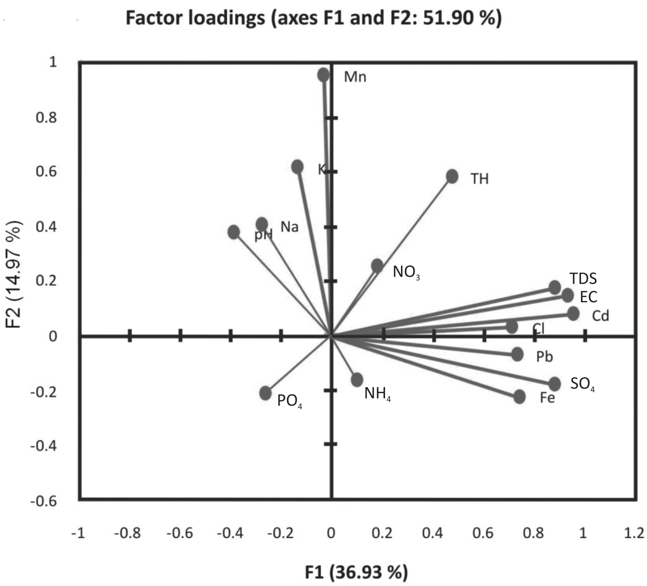

Figure 1: The ordination of the physicochemical parameters.

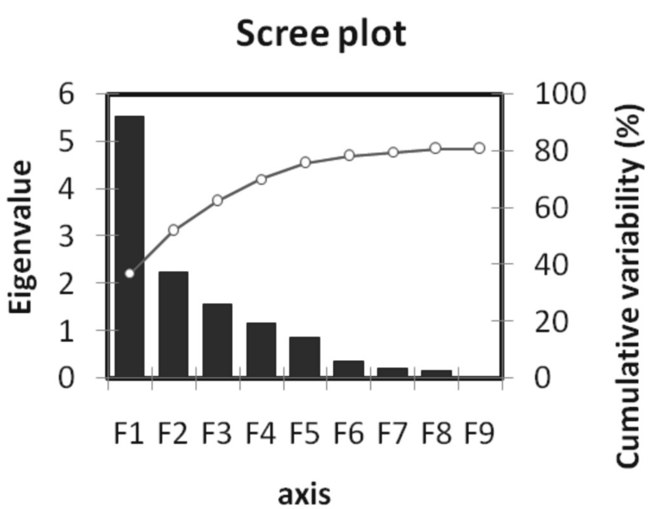

Figure 2: The Scree plot of the eigenvalues of factor analysis.

respectively. F1 contributing 36.93% of the total variance depicts the influence of EC, TDS, SO_4^{2-}, Cl^-, Fe, Pb, Cd (strong) and attributed to discharge of industrial effluents. F2 (51.90% of the total variance) explained for Mn (strong), TH, K^+ (moderate) and with Na^+ (weak), which can correspond with the goegenic sources. Factor 3 (62.34% of the total variance) which was positively loaded with PO_4 (strong), NH_4^+ (moderate) and negatively loaded with NO_3^- which can correspond with the agricultural activities while factor 4 (70.01% of the total variance) is negatively loaded with pH (moderate) and may be related with natural factors.

Cluster Analysis (CA)

Cluster analysis is one of the statistical tools to group similar pairs of correlation in a large symmetric matrix. Cluster analysis (CA) encompasses a number of different methods which organize objects (observations) into groups called clusters where the objects within the clusters are similar whereas objects in different clusters are dissimilar. In this study, the commonly applied average group and the Ward's clustering methods were used. The Euclidean distance was used as a similarity measure. Results of cluster analysis are represented using dendogram, that grouped all the 16 sampling points of the Damodar river into three statistically significant clusters. Dendrogram is displayed in Figure 3 showing clustering of sampling sites based on chemical analyses. Cluster 1 contains sampling points 1, 10, 11 and 15 which are located at close proximity to industrial area. Cluster 2 contains sapling points S6 and S7. These are located close to urban residential areas (densely populated) and the quality of the river water is influenced by domestic wastewater. In the Cluster 3 sampling points (2, 3, 4, 5, 8, 9, 12, 13, 14 and 16) are affected by agricultural activities and these sampling points receive pollution from non-point sources. Based on the similarity of water quality characteristics cluster analysis grouped the entire study area (sixteen sampling stations) into three clusters i.e., relatively less polluted, moderately polluted and highly polluted area.

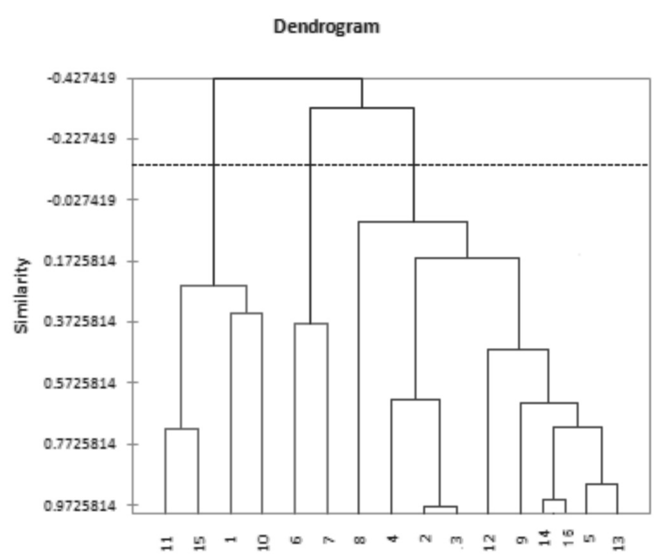

Figure 3: Dendrogram showing clustering of sampling sites based on chemical analyses.

Conclusion

Statistical methods have been employed to analyze the physicochemical characteristics of the river Damodar and the study reveals that most of the water samples of river system were found less polluted in heavy metal contamination profile and shows a trend in seasonal variation. The study reveals that pH values of river water are neutral to alkaline in nature. The study of factor analysis reveals four factors like industrial effluents, goegenic sources, agricultural activities and natural factors controlling their variability in waters of the river Damodar. Based on the similarity of river water quality characteristics cluster analysis grouped the entire study area into three clusters i.e., relatively less polluted, moderately polluted and highly polluted area. Hence, this study illustrates that multivariate statistical methods are an excellent exploratory tool for interpreting complex water quality data sets and for understanding spatial variations, which are useful and effective for water quality management.

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