# MONITORING AND ASSESSMENT OF RIVER POLLUTANTS : A STUDY ON RIVER DAMODAR AND RIVER BARAKAR OF INDIA USING FACTOR ANALYSIS

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## ABSTRACT

The factor analysis (FA) was carried out in order to find out the distribution modes of different physicochemical parameters along with heavy metals in water samples and to discriminate the different sources of pollution in river Damodar (India). Presence of heavy metals was detected in river water samples within the ranges of 0.00 - 188.75 µg l-1 (Pb), 0.00 - 65.09 µg l-1 (Mn), 0.00 -1452 µg l-1 (Fe) and 0.00 - 4 µg l-1 (Cd). High concentration of heavy metals along with sulphate was observed in the river Damodar at Chinakuri where the river receives mine wastes along with the wastewater from thermal power station. High concentration of nutrient indicates urban pollution at river Barakar near Barakar town. Thus, this study illustrated the usefulness of factor analysis for interpretation of complex environmental data set, water quality assessment, and identification of pollution sources. Study of factor analysis revealed that the industrial discharges, geogenic sources and natural factors strongly influence the water quality of the study area. The analyses revealed that the industrial discharges are responsible for the pollution of Pb, Fe and Cd in the river water along the Chinakuri industrial area.

**Key Words :** Water quality assessment, Factor analysis, Heavy metals, Barakar river, Damodar river

## INTRODUCTION

Rivers are highly heterogeneous at different spatial scales. Spatial and temporal variability in water chemistry in rivers is directly related to different factors like the natural[1] processes and anthropogenic[2,3] activities. Natural processes influencing water quality include precipitation, weathering of rocks, and sediment transport, whereas anthropogenic activities include urban development and industrialization in the catchment area. Effluent discharge resulting either from industrial, municipal, or agricultural activities containing toxic substances into aquatic environment creates problems of water pollution rendering water no longer fit for drinking, agriculture, and aquatic life[3,4]. The characterization of seasonal changes in water quality due to natural or anthropogenic inputs is an important aspect to study[5]. Damodar is an important river of West Bengal, India, serve as a variety of purposes including drinking, agriculture and industry. Industrial discharges from various industries like coke oven plants, sponge iron industries and several coal washeries discharges their thick effluents directly or indirectly into the river at different points in it course[6]. The present investigation deals with the spatial and temporal variations in hydrochemistry of river water and contamination assessment of river water by using factor analysis.

## MATERIAL AND METHODS

In order to obtain the research objective, samples were collected from twelve locations of Damodar river along with its tributaries the river Barakar near Barakar town ship region to evaluate the heavy metal contamination during three (summer, monsoon and winter) seasons. Four

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sites were selected along the Barakar river and eight sites were located along its main river. The river water samples were acidified with 0.5 ml of concentrated $HNO_3$ to prevent the precipitation of metals, and freeze for further physicochemical analysis. The samples preservation and analysis were performed according to Standard methods[7] . For the estimation of metals, the water and wastewater samples were digested with 10 ml concentrated $HNO_3$, filtered and analysed for Fe, Cd, Pb, Mn in AAS (GBC Avanta). Correlation study was performed for different water parameters including metals for analyzing the interrelations between them. Factor analysis (FA) based on a varimax rotation technique is used for this study as a statistical method of discussing variables and identifying the pollution sources by extracting minimum acceptable eigenvalue greater than 1. Statistical calculations are carried out for this study by XL Stat (version 10).

## RESULTS AND DISCUSSION

The minimum, maximum and mean concentrations along with standard deviation of the elements in water in various sampling points are presented in **Table 1**. Pearson's correlation (r) matrix of different effluent and water quality parameters is represented in **Table 2**. Factor loading matrix, eigenvalues and variances of factor analysis (FA) is represented in **Table 3**. The results revealed that in most of the sampling stations, water was alkaline in nature. The pH values were measured as 7.7-8.6 in the sampling stations. High pH of the river water may result in the reduction of heavy metal toxicity[8]. The increase of pH the nonindustrial downstream area could be due to agricultural run-off that is usually alkaline in nature. Electrical conductivity, which is a measurement of the ionic strength of solution, varies between 180 - 610 µS/cm. Higher concentration of TDS (349.76 $mgl^{-1}$) was observed in the river water near the site chinakuri. Various large and small industries are concentrated in these areas.

Phosphate concentration (1.60 $mgl^{-1}$) is maximum at station Gobindapur charmana due to the nonpoint agricultural sources. The maximum nitrate concentration (2.80 $mgl^{-1}$) was observed in the Damodar river at station Madanpur due to the nonpoint agricultural sources. High concentration of chloride (41.11 $mgl^{-1}$) was observed in the river Barakar; at this point the river receives urban wastes irrespective of the season. High concentration of sulphate (51.15 $mgl^{-1}$) was observed in the river Damodar station at Chinakuri; here the river Damodar receives mine wastes. The data obtained on the physicochemical parameters of the river water were subjected to correlation analysis. The correlation of different water quality parameters is represented in **Table 2**. Correlation study (r) among the different water quality parameters including metals revealed positive correlations ($p<0.05$) between EC - TDS (0.962), EC - Pb (0.535), EC - Cd (0.371), TDS - Pb (0.491) and $Cl^-$ - $SO_4^{2-}$ (0.743), which may be explained by similar pattern of distribution (irrespective of season) due to their interdependence/influence on each other.

The high value of Fe (1452 µg $l^{-1}$) concentrations was found at Barakar in summer than winter and monsoon season respectively. The maximum lead (Pb) concentrations (188.75 µg $l^{-1}$) were found in the main stream the river Damodar at Chinakuri as this site located near the discharge point of thermal power station. The maximum value of Pb observed in winter season while in summer in some areas it exhibit low concentration. The low concentration in some sampling site may be due to the less soluble of lead containing minerals in natural water[9,10]. The manganese concentration in the study area ranges between 0.0 - 65.09 µg $l^{-1}$. High concentration of cadmium (3.25 µg $l^{-1}$) was observed in the river Damodar at Chinakuri. It may be due to coal- combustion which is very frequent in industries like thermal power station which is located near this site. The major source of Cd is the coal combustion, metal industry and waste incineration[11]. Sampling covered both monsoon and non monsoon seasons and it was observed that generally the water quality in monsoon season was slightly better than that in nonmonsoon seasons due to flushing effect. Study reveals that positive correlations exist between elemental pairs Pb-Cd (r=0.762), Pb-Fe (r=0.264), Cd-Fe(r=0.363). It is can, thus, be

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

| | | S1 | S2 | S3 | S4 | S5 | S6 | S7 | S8 | S9 | S10 | S11 | S12 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | Min | 8.2 | 7.7 | 7.9 | 7.8 | 7.7 | 7.8 | 8.2 | 7.7 | 7.9 | 8.3 | 7.8 | 7.8 |
| | Max | 8.4 | 7.9 | 8.3 | 8.1 | 7.9 | 8.1 | 8.9 | 7.8 | 8.3 | 8.6 | 7.9 | 8.1 |
| | Mean | 8.3 | 7.8 | 8.1 | 7.9 | 7.8 | 7.9333 | 8.53 | 7.7333 | 8.14 | 8.4667 | 7.86 | 7.9 |
| | SD | 0.10 | 0.10 | 0.20 | 0.17 | 0.10 | 0.15 | 0.35 | 0.06 | 0.21 | 0.15 | 0.05 | 0.17 |
| EC | Min | 450 | 310 | 420 | 350 | 510 | 450 | 450 | 290 | 310 | 180 | 240 | 190 |
| | Max | 500 | 460 | 490 | 410 | 540 | 610 | 550 | 410 | 460 | 260 | 273 | 270 |
| | Mean | 476.7 | 363.3 | 453.3 | 386.7 | 530.0 | 533.3 | 490.0 | 353.3 | 363.3 | 226.7 | 257.7 | 236.7 |
| | SD | 25.2 | 83.9 | 35.1 | 32.1 | 17.3 | 80.2 | 52.9 | 60.3 | 83.9 | 41.6 | 16.6 | 41.6 |
| TDS | Min | 243.5 | 167.5 | 267.3 | 142.7 | 306.2 | 306.5 | 242.3 | 143.1 | 209.5 | 141.0 | 156.0 | 110.0 |
| | Max | 382.5 | 276.7 | 320.5 | 258.3 | 365.2 | 385.5 | 358.3 | 272.8 | 322.3 | 210.4 | 191.0 | 206.9 |
| | Mean | 321.7 | 210.4 | 295.1 | 217.5 | 339.5 | 349.8 | 317.3 | 224.9 | 253.6 | 187.1 | 175.2 | 171.0 |
| | SD | 71.10 | 58.24 | 26.68 | 64.84 | 30.23 | 40.04 | 65.07 | 71.19 | 60.29 | 39.95 | 17.75 | 53.08 |
| Pb | Min | 95.24 | 77.056 | 124.7 | 9.75 | 116.25 | 0.318 | 14.6 | 0.148 | 3.025 | 5.08 | 0 | 0.558 |
| | Max | 102.80 | 97.05 | 149.34 | 50.20 | 188.75 | 3.76 | 29.90 | 0.40 | 6.70 | 5.73 | 0.00 | 0.90 |
| | Mean | 99.05 | 87.06 | 139.08 | 23.90 | 141.50 | 1.98 | 19.90 | 0.26 | 4.53 | 5.41 | 0.00 | 0.75 |
| | SD | 3.78 | 10.00 | 12.83 | 22.80 | 40.95 | 1.72 | 8.67 | 0.13 | 1.92 | 0.32 | 0.00 | 0.17 |
| Mn | Min | 1.16 | 0.00 | 0.55 | 1.45 | 6.59 | 0.41 | 6.00 | 21.01 | 0.10 | 2.50 | 0.00 | 0.75 |
| | Max | 1.89 | 4.34 | 9.75 | 3.54 | 8.54 | 24.25 | 65.09 | 22.00 | 8.50 | 27.75 | 0.28 | 1.00 |
| | Mean | 1.42 | 1.75 | 4.33 | 2.59 | 7.57 | 15.13 | 39.86 | 21.35 | 3.20 | 12.67 | 0.18 | 0.83 |
| | SD | 0.41 | 2.29 | 4.81 | 1.06 | 0.97 | 12.87 | 30.48 | 0.56 | 4.61 | 13.32 | 0.16 | 0.14 |
| Cd | Min | 0.825 | 1.5 | 0.25 | 0.25 | 1 | 0 | 0.15 | 0.175 | 0 | 0.36 | 0 | 0 |
| | Max | 2.25 | 2.5 | 0.8 | 0.75 | 3.25 | 0.468 | 0.502 | 0.5 | 0.28 | 0.94 | 0 | 0.582 |
| | Mean | 1.33 | 1.83 | 0.52 | 0.47 | 2.08 | 0.25 | 0.38 | 0.32 | 0.14 | 0.60 | 0.00 | 0.35 |
| | SD | 0.80 | 1.88 | 0.28 | 0.26 | 1.13 | 0.24 | 0.20 | 0.17 | 0.14 | 0.30 | 0.00 | 0.31 |
| Fe | Min | 1175 | 451 | 120 | 422 | 281 | 352 | 0 | 2 | 62 | 43 | 517 | 452 |
| | Max | 1452 | 958 | 196 | 550 | 461 | 985 | 173 | 24 | 76 | 69 | 710 | 540 |
| | Mean | 1357.67 | 635.67 | 152.67 | 475.33 | 398.00 | 656.00 | 57.67 | 11.90 | 67.17 | 54.73 | 636.67 | 502.67 |
| | SD | 158.22 | 280.14 | 39.11 | 66.61 | 101.42 | 317.24 | 99.88 | 10.97 | 7.93 | 13.12 | 104.51 | 45.49 |
| $NO_3$ | Min | 0.27 | 0.40 | 0.00 | 0.15 | 0.00 | 0.28 | 0.64 | 0.76 | 0.19 | 0.35 | 0.21 | 0.68 |
| | Max | 0.79 | 1.17 | 0.26 | 0.97 | 0.69 | 0.58 | 2.80 | 1.40 | 0.86 | 1.50 | 1.24 | 2.77 |
| | Mean | 0.55 | 0.68 | 0.09 | 0.48 | 0.30 | 0.45 | 1.41 | 1.12 | 0.43 | 0.77 | 0.74 | 1.43 |
| | SD | 0.26 | 0.43 | 0.15 | 0.43 | 0.36 | 0.16 | 1.20 | 0.33 | 0.37 | 0.64 | 0.52 | 1.16 |
| Cl | Min | 10.31 | 18.25 | 16.20 | 23.34 | 36.30 | 19.42 | 9.35 | 25.00 | 2.26 | 6.46 | 8.59 | 8.21 |
| | Max | 14.41 | 21.35 | 19.20 | 41.11 | 39.53 | 31.20 | 12.32 | 33.50 | 14.32 | 7.98 | 15.66 | 10.51 |
| | Mean | 12.42 | 19.84 | 17.64 | 31.27 | 38.18 | 24.37 | 10.66 | 29.30 | 8.37 | 6.98 | 10.98 | 9.61 |
| | SD | 2.05 | 1.55 | 1.50 | 9.04 | 1.68 | 6.11 | 1.51 | 4.25 | 6.03 | 0.87 | 4.05 | 1.23 |
| $SO_4$ | Min | 16.55 | 12.42 | 11.74 | 25.54 | 47.25 | 22.77 | 17.17 | 18.34 | 13.55 | 20.46 | 11.39 | 18.17 |
| | Max | 17.12 | 17.77 | 17.71 | 41.35 | 51.15 | 32.96 | 22.37 | 31.57 | 17.55 | 28.32 | 12.68 | 28.29 |
| | Mean | 16.81 | 15.69 | 15.03 | 33.01 | 49.21 | 26.90 | 20.30 | 23.52 | 15.40 | 25.67 | 11.90 | 22.26 |
| | SD | 0.29 | 2.87 | 3.03 | 7.94 | 1.95 | 5.36 | 2.76 | 7.06 | 2.02 | 4.51 | 0.68 | 5.33 |
| $PO_4$ | Min | 0.42 | 0.61 | 0.00 | 0.02 | 1.00 | 0.02 | 0.00 | 0.00 | 0.04 | 0.00 | 0.50 | 0.25 |
| | Max | 0.52 | 1.21 | 0.03 | 0.12 | 1.12 | 0.56 | 0.05 | 0.07 | 0.12 | 0.12 | 1.60 | 0.64 |
| | Mean | 0.47 | 0.93 | 0.01 | 0.07 | 1.06 | 0.34 | 0.03 | 0.04 | 0.07 | 0.04 | 0.87 | 0.46 |
| | SD | 0.05 | 0.30 | 0.01 | 0.05 | 0.06 | 0.28 | 0.03 | 0.04 | 0.04 | 0.07 | 0.64 | 0.20 |

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

| Variables | pH | EC | TDS | Pb | Mn | Cd | Fe | $NO_3^-$ | $Cl^-$ | $SO_4^{2-}$ | $PO_4^{3-}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| pH | 1 | | | | | | | | | | |
| EC | 0.054 | 1 | | | | | | | | | |
| TDS | 0.215 | **0.962** | 1 | | | | | | | | |
| Pb | -0.068 | 0.535 | 0.491 | 1 | | | | | | | |
| Mn | 0.292 | 0.448 | 0.440 | -0.198 | 1 | | | | | | |
| Cd | -0.165 | 0.371 | 0.307 | **0.762** | -0.190 | 1 | | | | | |
| Fe | -0.127 | 0.204 | 0.181 | 0.264 | -0.399 | 0.363 | 1 | | | | |
| $NO_3^-$ | 0.157 | -0.407 | -0.388 | **-0.583** | 0.481 | -0.295 | -0.185 | 1 | | | |
| $Cl^-$ | **-0.641** | 0.503 | 0.341 | 0.364 | 0.106 | 0.428 | 0.007 | -0.347 | 1 | | |
| $SO_4^{2-}$ | -0.246 | 0.357 | 0.321 | 0.242 | 0.082 | 0.447 | -0.099 | -0.171 | **0.743** | 1 | |
| $PO_4^{3-}$ | -0.507 | 0.050 | -0.008 | 0.374 | -0.346 | **0.633** | 0.515 | -0.136 | 0.255 | 0.216 | 1 |

*Values in bold are significant at $P < 0.05$*

inferred that Pb, Fe, Cd were introduced into the water column from a common source.

**Table 3 : Factor loading matrix, eigenvalues and variances**

| | F1 | F2 | F3 |
|---|---|---|---|
| pH | -0.316 | 0.457 | **0.504** |
| EC | **0.754** | 0.588 | 0.149 |
| TDS | **0.670** | 0.639 | 0.275 |
| Pb | **0.748** | -0.072 | 0.306 |
| Mn | -0.079 | **0.886** | -0.305 |
| Cd | **0.736** | -0.229 | 0.081 |
| Fe | **0.331** | -0.324 | 0.319 |
| $NO_3$ | **-0.596** | 0.157 | -0.334 |
| Cl | **0.734** | 0.036 | -0.642 |
| $SO_4$ | **0.541** | 0.087 | -0.419 |
| $PO_4$ | 0.520 | **-0.596** | -0.057 |
| Eigenvalue | 3.822 | 2.303 | 1.374 |
| Variability (%) | 34.744 | 20.941 | 12.490 |
| Cumulative % | 34.744 | 55.685 | 68.175 |

Values in bold set indicates significant loading

**Factor analysis**

Multivariate statistical techniques are used in analytical chemistry to quantify the relationships between more than two variables under simultaneous consideration of their interactions[12]. Factor analysis attempts to identify few factors that are responsible for the correlation among a large number of variables, it is also classified as a data reduction technique. The varimax rotated factor analyses were calculated using eigenvalues greater than 1.0 applied to the study. The purpose of the factor analysis (FA) in this study is the description of the observed variables in complex environmental compartments by finding summarizing factors. 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[13]. Various factors affect the Damodar river water quality and this affected water quality can be evaluated by the factor analysis[14]. Component loadings of principal components for each season are presented in **Fig. 1.** Factor 1 which was moderate positively loaded with EC, TDS, Pb, Cd, $SO_4^{2-}$ and $Cl^-$; positively loaded with Fe (week); and negatively loaded with nitrate $NO_3^-$ **(Table 3)**, seemed to be related to urban and industrial sources, both of which are the results of anthropogenic activities. The strong positively loaded was Mn and the moderate negatively loaded was $PO_4^{3-}$ in factor 2 which represented the mineral-related hydrochemistry of the surface water. Factor 3 which is relatively small comparison with other factors the pH (moderate positively loaded) was found, which may be due to natural sources. These parameters were determined that industrial discharge, geogenic sources and natural factors strongly influences the water quality of the study area.

## CONCLUSION

There were certain changes observed in the hydrochemistry of river water and industrial effluents discharge has been identified as major pollutant sources. In general the study reveals that in downstream area, 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 results of the present study indicate a remarkable increase in pollution along with heavy metals concentration at Chinakuri of river Damodar due to the increased loading of the indiscriminate and long-term disposal of effluents from thermal power plant and mining areas. From the factor analysis it was observed that the industrial discharges, geogenic sources and natural factors strongly influence the water quality of the study area.

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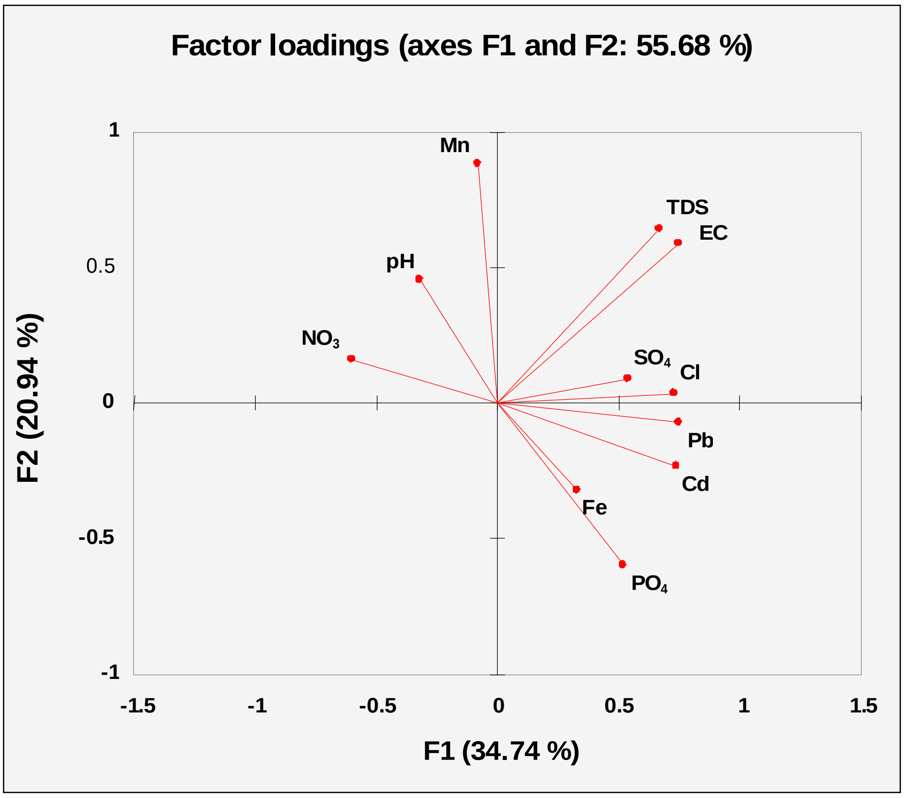


**Fig 1.** The ordination of the physicochemical parameters

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