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Assessment of Pulsating Water Quality of Surface Water Body, Using Multivariate Statistical Techniques: A Case Study of The Mahanadi Water System

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ABSTRACT

The surface water quality of Mahanadi river system in Odisha was analysed by applying the multivariate statistical techniques including cluster analysis (CA), factor analysis (FA) and principal component analysis (PCA). Agglomerative hierarchical cluster analysis (AHC) grouped 13 sampling sites into three clusters namely less polluted (LP), moderately polluted (MP), and highly polluted (HP) sites under the similarity of surface water quality parameters. The application of factor analysis/ principal component analysis to the evaluated data set of three different clusters, generates four PCs for LP and MP and two PCs for HP having eigen value >1. The PCs obtained from factor analysis indicates that the increase in load of nitrate (NO_3-N); nitrite (NO_2-N); ammonical (NH_4-N), total Kjeldahl nitrogen (TKN), total phosphorous (TP) and decrease in DO, pH level of water in HP and MP sites, display the intensity of organic pollution in the river that are mainly attributed to agriculture runoff, industrial effluents and regional anthropogenic contributions from both point and non-point sources. Thus these methods are believed to be valuable for water resource manager to identify the complex nature of water quality issues and determine the relative precedence to enhance the water quality of surface water body.

Keywords: Mahanadi River, Industrial/Urban sewage, Cluster analysis, Principal Component analysis, Statistical analysis, Water quality.

INTRODUCTION

The water environment quality is a very important and is a subject of major concern for economic development of any country. The water resource problems related to degradation have increasingly been serious because of rapid industrialisation and urban sprawl. Anthropogenic influences such as urbanisation, industrial and agricultural activities, increasing consumption of water recourses along with natural process i.e change in precipitation inputs, erosion, effectively deteriorate surface water quality and impair their uses for drinking, industrial, agriculture, recreating and other purposes [1,2]. In order to study spatial and temporal variation in surface water chemistry a regular monitoring program that will provide a representative and reliable estimation of the quality of surface water is highly essential [3]. Thus monitoring program including frequent water samplings at many sites and determination of large number of physicochemical parameters are usually conducted resulting in a large data matrix, which needs a complex data interpretation [4].

The application of different multivariate statistical techniques, such as cluster analysis (CA) , principal component analysis (PCA) , factor analysis (FA) , helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied system, allows the identification of possible factors that influences water environment system, and offers a valuable tool for reliable management of water resources [5,6].The statistical method applied in this study can be used to assess the relationship between variable and possible pattern in distribution of measured data. In this study we mainly used CA to group water body into several zones with different water quality and PCA to find the most important factor that describe the natural and anthropogenic influences.

The Mahanadi watershed is the most developed and urbanised region in the state of Odisha. The increasing deterioration of water quality of the watershed is mainly attributed to the uncontrolled and improper disposal of solid and toxic waste from industrial effluents, agricultural runoff and other human activities. This alarming water pollution not only causing degradation of water quality but also threatens human health and balance of aquatic ecosystem, and economic development of the state.

In the present study, data matrix obtained during 4 years monitoring program (2007 to 2010) is subjected to different multivariate statistical approach to extract information about the similarities or dissimilarities between sampling sites, and the influences of possible sources on water quality parameters of the Mahanadi watershed. The specific objectives of the research are to

i. classify the watershed into several zones with different water quality.
ii. extract and establish the parameters that are most important in assessing variation in water quality of different zones,
iii. find out a good approach to assess the water quality of each cluster reasonably that can be helpful to the managers to take the effective measures to manage the water resource respectively.

Study sites: The river Mahanadi is one of the major inter-state east flowing rivers in peninsular India. It originates at an elevation of about 442 m. above Mean Sea Level near Pharsiya village in the Amarkantak hills of Bastar Plateau lying extreme south of Raipur district of Chattisgarh. The basin extends over an area approximately 141,600 km^2, out of which 65,628 km^2 lies in Odisha, occupying 42.15% of the state geographical area. The total length of the river from its origin to confluence of the Bay of Bengal is about 851 km., of which, 357 km. is in Chattisgarh and the balance 494 km. in Odisha. The average annual discharge is 1,895 m^3/s, with a maximum of 6,352 $m^3 s^{-1}$during the summer monsoon. Minimum discharge is 759 $m^3 s^{-1}$ and occurs during the months October through June. The geographical co-ordinates of the Mahanadi basin in Odisha lies between $82^0$10' to $86^0$50' East longitudes and $19^0$30' to $22^0$15' North latitudes (Figure 1). It flows over different geological formations of Eastern Ghats and adjacent areas and joins the Bay of Bengal after dividing into different branches in the deltaic area. The main branches of the river Mahanadi meet the Bay of Bengal at Paradip and Nuagarh (Devi estuary). Along its course, the Mahanadi receives effluents from different industrial and urban centres such as Sambalpur, Bauda, Cuttack, Choudwar, Jagatpur and Paradip in Odisha. The various industries operating in the Mahanadi basin are listed in the (Table 1). The details of the monitoring stations (MR) and the major urban settlements are shown in the schematic diagram (Figure-2).

In the recent past a lots of work has been carried out on the role of different urban and industrial effluents upon the water quality of the Mahanadi river system [7-9], as well as other water bodies in India [10,11]. The present study deals with the loading of 21 different physicochemical parameters in Mahanadi waters covering a short range i.e. Hirakud reservoir (MR1) to Gatiroutpatna (MR13), a station located further downstream of Cuttack, within the course of the river in the state of Odisha. The physicochemical parameters such as NO_2-N, NO_3-N, NH_4-N, TKN and total phosphorous (TP) were analysed, along with pH, DO, BOD, COD, TSS, TDS, and other metals such as Zn, Ni, Pb and Cu etc., in order to assess the impact of different effluents upon the quality of the river water.

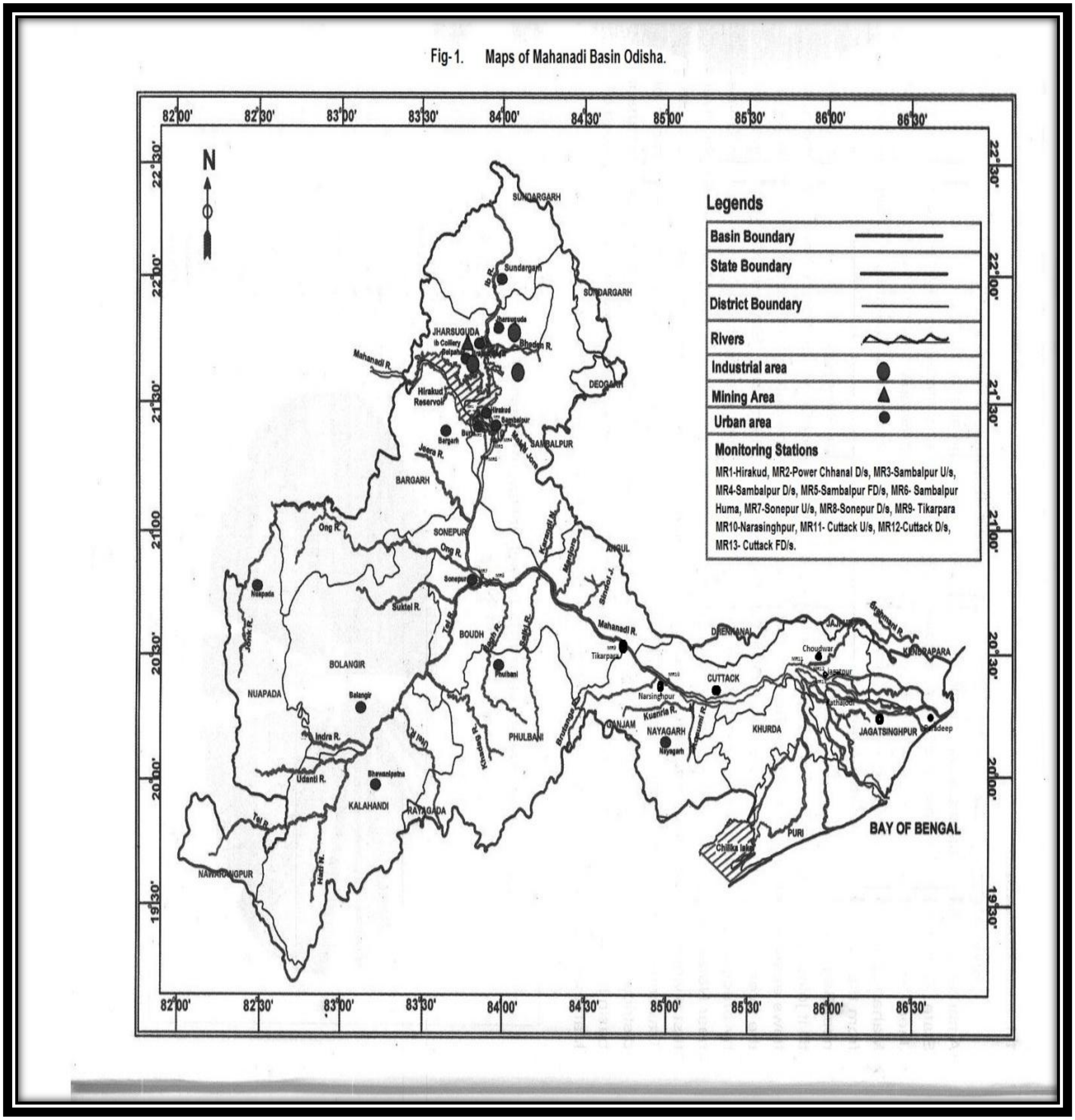

Figure 1. Map of Mahanadi basin in Odisha (India), indicating monitoring stations

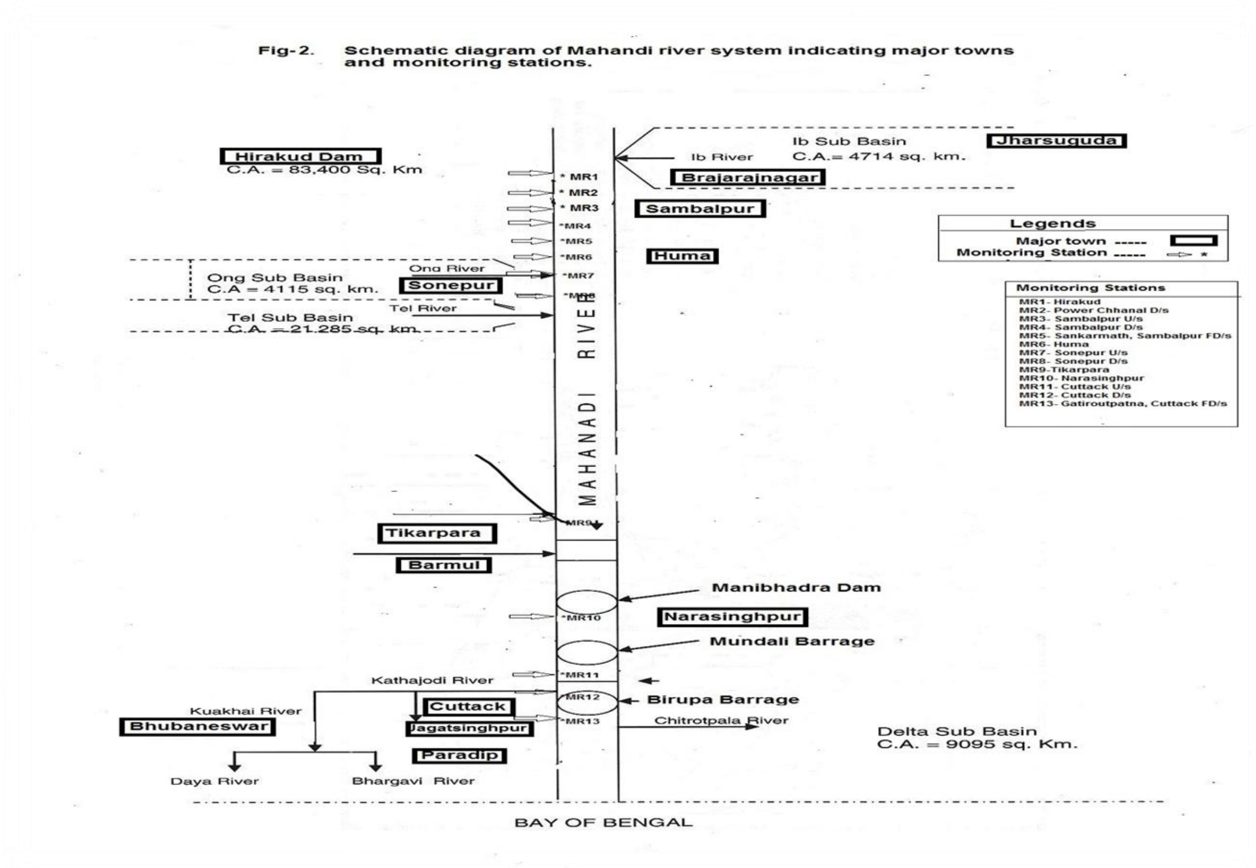

Fig 2: Schematic Diagram of the Mahanandi River system indicating major towns and monitoring station

Table-1. Major industries operating in the Mahanadi Basin in Odisha.

Name of the industries and Location	**Products**
A) Mahanadi	
Arati Steel Ltd., Athagarh.	Steel
Hindalco Industries Ltd., Sambalpur.	Power
Hindalco Industries Ltd., (Smelter) Sambalpur.	Aluminium Smelter Plant
Orissa Power generation Cooperation (OPGC), Banharpali.	Power
Bargarh Co-operative Sugar Mills Ltd., Bargarh.	Sugar
ACC Cement, Bargarh.	Cement
Bijayananda Co-operative Sugar Mills Ltd., Bolangir.	Sugar
Nayagarh Sugar Complex Ltd., Nayagarh.	Sugar
Cosboard Industries Ltd., Cuttack.	Cardbpard and paper
SMV Beverages Pvt Ltd.,Cuttack.	Softdrinks
Paradip Phosphate Ltd., Jgatsinghpur.	Phosphatic Fertilisers
IFFCO Ltd., Jagatsinghpur.	Phosphatic Fertilisers
Skol Breweries Ltd., Jgatsinghpur	Beer
B) Ib	
Vedanta Aluminium Ltd., Jharsuguda	Alminium Smelter Plant
Sterlite Energy (P) Ltd., Jharsuguda	Power
TRL Krosaki Refractories., Belpahar	Refractories
Ultar Tech Cement Ltd., Jharsuguda	Cement
Bhusan Power and Steel Ltd., Jharsuguda	Iron and Steel, Power
C) Birupa	
Indian Metal & Ferro Alloys Ltd. (CPP), Choudwar	Power
Indian Metal & Ferro Alloys Ltd. (Ferroalloys), Choudwar	Chargechrome

MATERIALS AND METHODS

Sampling and Parameters: Water samples were collected from 13 stations along the course of the Mahanadi river system, starting from the Hirakud reservoir (MR1) to Cuttack FD/s at Gatiroutpatna (MR13). The sampling strategy was designed in such a way to cover a wide range of determinants at key sites that accurately represent the water environment quality of the river systems and account for tributary inputs that can have important impacts upon downstream water quality. Various water quality parameters from the monitoring stations were analysed in four different seasons from 2007 to 2010. The mean value of the data sets was taken into consideration for evaluating the pollution load in the water system. The measured parameters include field pH, dissolved oxygen (DO), free ammonia (NH_3-N), nitrate (NO_3−N), nitrite (NO_2−N), ammonical (NH_4-N), total Kjeldahl nitrogen (TKN), chemical oxygen demand (COD), biochemical oxygen demand (BOD), total phosphorous (TP), TSS, TDS, fluoride, Fe, Cr, Cd, Ni, Zn, Pb, Cu, and total alkalinity (TA). The summary basic statistics of the dataset is presented in (Table 2). Statistical analyses, viz. cluster analyses, principal component analysis were carried out for 21 parameters at 13 monitoring stations and the data were processed using XLSTAT-11.5 statistical package.

Table-2. Minimum, Maximum, Mean and Standard deviation of water quality parameters at different monitoring stations from 2007 to 2010.

Variable	Observations	Minimum	Maximum	Mean	Std. deviation
pH	13	7.420	7.900	7.730	0.116
DO	13	7.170	8.200	7.785	0.256
BOD	13	0.950	2.600	1.436	0.504
COD	13	7.400	19.450	11.614	3.653
NH_4- N	13	0.590	1.370	0.925	0.237
NH3-N	13	0.026	0.065	0.043	0.011
NO3-N	13	1.251	2.578	1.923	0.392
NO_{2-} N	13	0.282	0.625	0.438	0.094
TP	13	0.014	0.390	0.081	0.100
TKN	13	4.800	15.910	9.252	3.144
TDS	13	110.000	176.000	126.019	17.962
TSS	13	13.250	49.250	25.411	9.754
F^-	13	0.250	0.402	0.301	0.044
Fe	13	0.111	0.912	0.437	0.242
Ni	13	0.003	0.012	0.008	0.003
Cr	13	0.024	0.074	0.039	0.014
Zn	13	0.009	0.043	0.018	0.011
Cd	13	0.001	0.002	0.002	0.000
Pb	13	0.004	0.011	0.007	0.002
Cu	13	0.003	0.017	0.007	0.005
TA	13	74.000	101.500	90.154	7.782

Statistical analysis: In recent years, various statistical procedures based on multivariate data taken from river system have been used to formulate environmental classifications, which help for a better understanding of the chemical processes occurring in the river environment. For a better understanding of the natural and anthropogenic fluxes responsible for the characterization of water quality in the Mahanadi river system. Principal component analysis (PCA) and cluster analyses (CA) were carried out for data set obtained from four different years from 2007 to 2010. The factor analyses were calculated using eigen values greater than 1.0, is considered the significant influences towards the geo-chemical processes [12]. The hierarchical clustering was carried out from data normalized to a zero mean and using Euclidian distances as a measure of similarity [13]. Ward's method was selected because it possesses a small spacedistorting effect and accesses more information on cluster content [14]. The results indicate that the CA technique offers a reliable classification of surface water in the whole region and make it possible to design a future spatial sampling strategy in a optimal method, that can reduce the number of monitoring sites.

Cluster Analysis: Cluster analysis (CA) is used to develop meaningful aggregations or groups of entities based on a large number of interdependent variables. The resulting clusters of objects should exhibit high internal (within-cluster) homogeneity and high external (between clusters) heterogeneity [15]. Of all cluster analysis, hierarchical cluster is most common approach. In the study, hierarchical agglomerative CA was performed based on the normalized data set (mean of observations over the whole period) by means of the Ward's method using Euclidean distances as a measure of similarity. The spatial variability of water environment quality in the whole river basin was determined from CA, which divides a large number of objects into smaller number of homogenous groups on the basis of their internal correlations [16].

Principal component analysis / Factor analysis: Factor analysis, which includes PCA is a very powerful technique applied to reduce the dimensionality of a dataset consisting of a large number of interrelated variables, while retaining as much as possible the variability presented in dataset [17]. These reduction is achieved by transforming the dataset into a new set of variables called the principal components (PCs), which are orthogonal (non-correlated) and are arranged in decreasing order of importance. Mathematically, the PCs are computed from covariance or other cross-product matrix, which describes the dispersion of the multiple measured parameters to obtain eigen values and eigenvectors. Principal components are the linear combinations of the original variables and the eigenvectors [18]. PCA can be used to reduce the variable numbers and explain the same amount of variance with fewer variables (principal components) [19]. Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable [20]. This study comprises application of multivariate statistical techniques to analyze water quality dataset obtained from the Mahandi River in Odisha. Statistical calculations were performed using the "XLSTAT- 11.5 for Windows.

RESULTS AND DISCUSSION

Spatial similarities and site grouping: In this study, sampling sites classification was performed by the use of cluster analysis. The relationships among the stations were obtained through cluster analyses using Ward's method (linkage between groups), with Euclidian distance as a similarity measure and were synthesized into dendrogram plots. Since we used hierarchical agglomerative cluster analysis, the number of clusters was also decided by water environment quality, which is mainly effected by land use and industrial structure. The physicochemical parameters like pH, DO, BOD, COD, NH_4- N, NH_3-N, NO_3-N, NO_2-N, total Kjeldahl –N (TKN), total phosphorous (TP), TDS, TSS, F, Fe, Ni, Cr, Zn, Cd, Pb, Cu and total alkalinity (TA) were used as variables and showed a sequence in their association, displaying the information as degree of contamination. Based on the result of the cluster analysis, the 13 monitoring stations are grouped into three different clusters namely less polluted (LP) sites, moderately polluted (MP) and highly polluted (HP) sites, depending on the similarity of their water quality characteristics. Grouped stations under each cluster are depicted in Ward's minimum variance dendrogram (Figure 3).

Agglomerative Hierarchical Cluster Analysis (AHC)

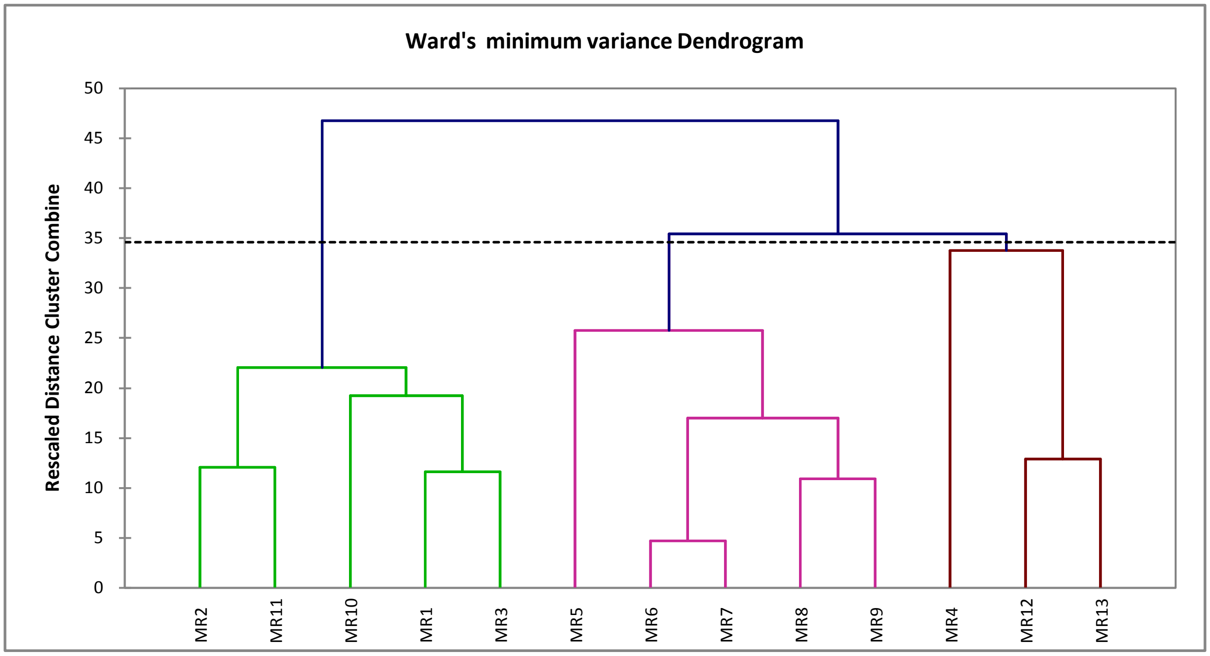

Figure 3. Dendrogram showing clustering of monitoring sites according to surface water quality characteristics of the Mahanadi river basin

Cluster- I (MR 1-2-3-10-11): Monitoring sites, mainly located in between the Sambalpur and Cuttack city namely, (MR 1-2-3-10-11) are clustered in this group. The impact of human beings activities on the riverine ecosystem is relatively low. Although the mining and the direct discharge of domestic water contaminated the river water system, cluster I corresponds to less polluted (LP) site, because the inclusion of sampling location suggests the self purification and assimilative capacity of the river are strong.

Cluster- II (MR 5-6-7-8-9): This cluster sites mainly located in between Sambalpur and Cuttack city. These sites are classified as moderately polluted (MP). From Sankarmath (MR5), further downstream of Sambalpur to Sonpur D/s (MR8) (about 78 km, along the river course), the river travels through a region with no major urban settlement or waste water outfall. Sonepur is the confluence of Mahanadi with two of its important right bank tributaries namely Ong and Tel. Thus the water quality at Sonepur U/s (MR7), which is immediately downstream of Ong confluence, is quite satisfactory. Although Sonpur is a district head quater, the deterioration of water quality at Sonpur D/s (MR8) is not as much as expected. This is primarily because Sonepur D/s on the Mahanadi is actually the downstream of its confluence with Tel, which has significant annual average flow with very low pollution load. From Sonepur D/s (MR8) to Tikarpara (MR9) does not have any industry or urban settlement on its banks and also there is no major wastewater outfall. From Tikarpara (MR9) to Narasinghpur (MR10) (about 60 km), the river flows completely undisturbed.

Cluster- III (MR 4-12-13): This cluster mainly includes Sambalpur D/s (MR4), Cuttack D/s (MR12) and (MR 13) at Gatiroutpatna, further downstream of Cuttak. These sites are classified as highly polluted (HP). During its course from Narasinghpur to Cuttack the river enter into deltatic region characterised by high population density and intense agricultural activities. The deterioration in the water quality in these monitoring stations is mostly due to untreated domestic wastewater, industrial effluents and agricultural runoffs.

Data structure determination and source identification: Principal component analysis/factor analysis was performed on the normalized data sets separately for the three different regions, viz., LP, MP and HP, as delineated by CA techniques, to compare the composition structure between analyzed water samples and the factors loadings of each variable. PCA of the three data sets yield four PCs for LP and MP sites while two PCs were obtained for HP sites with each cases having eigen values >1. An eigen value gives a measure of the significance for the factor, which with highest eigen value is the most significant. Eigen values of 1.0 or greater are considered significant [21].The 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 [22].

For the data set pertaining to LP sites, four PCs were obtained having eigen value >1 as shown in the screen plot for LP sites (Figure-4). Among four PCs, (Table-3), PC1, explaining 38.38% of the total variance, has moderate positive loadings on F^-, TP, Cd and Strong positive loading on NH_4-N, NH_3-N, Cr, and Zn which is attributed to localized anthropogenic input and also due to deamination of nitrogen containing organic compounds rather than river runoffs. PC2, explaining 25.66% of the total variance, moderate positive loadings on COD, Zn, Cu ,strong positive loadings on TDS, Pb and strong negative loading on Cd. PC3, explaining 23.59% of the total variance, has strong positive loadings on Fe, strong negative loading on pH, BOD, F^-, moderate positive loading on DO . PC2 and PC3 represent organic pollution from domestic waste and nonpoint source pollution. PC4, explaining the lowest variance (12.36%), has moderate loadings on TA, strong positive loading on TKN, which is due to normal biological degradation products of nitrogenous organic matter.

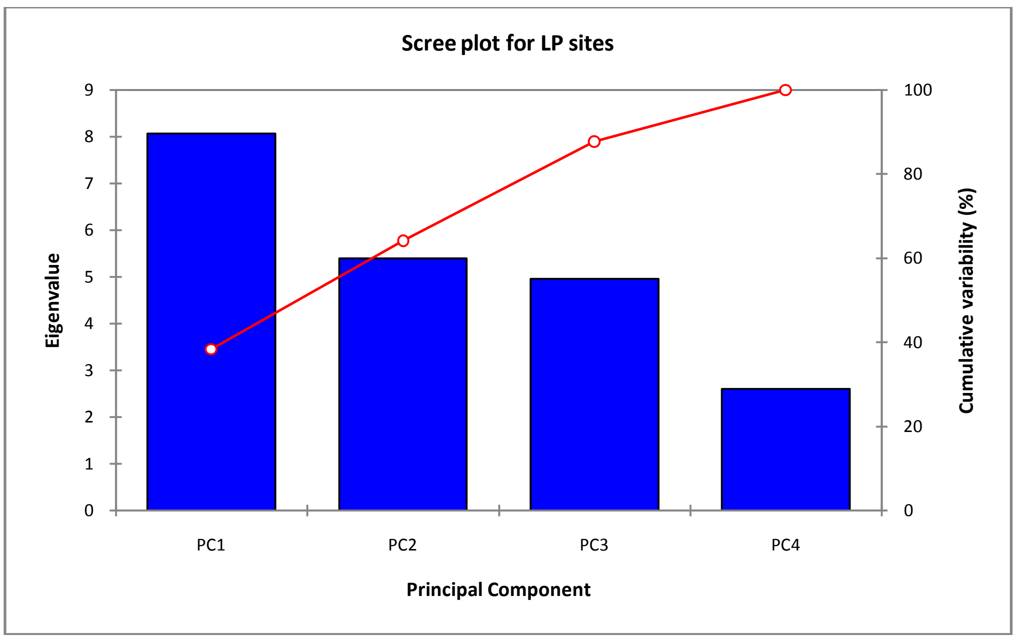

Figure-4 Screen plot for LP sites

Table 3 Principal ComponentAnalysis of LP sites.

Variables	**PC1**	**PC2**	**PC3**	**PC4**
pH	-0.386	0.326	**-0.807**	-0.307
DO	0.488	-0.469	**0.655**	0.336
BOD	0.128	0.231	**-0.928**	0.263
COD	-0.467	**0.665**	**-0.528**	0.246
NH_4- N	**0.892**	0.408	0.098	0.170
NH_3-N	**0.836**	0.255	-0.369	0.316
NO_3-N	**-0.780**	**-0.596**	-0.183	-0.058
NO_2-N	**-0.791**	**-0.568**	-0.215	-0.072
TP	**0.560**	0.006	-0.304	**-0.770**
TKN	-0.084	0.114	**-0.522**	**0.841**
TDS	**-0.523**	**0.769**	0.238	-0.279
TSS	-0.138	**-0.684**	**-0.560**	-0.448
F^-	**0.593**	-0.178	**-0.773**	0.142
Fe	-0.014	0.071	**0.959**	0.273
Ni	**-0.716**	**-0.625**	-0.130	0.282
Cr	**0.989**	0.020	-0.102	-0.107
Zn	**0.783**	**0.594**	-0.172	0.059
Cd	**0.561**	**-0.790**	0.150	0.196
Pb	**-0.524**	**0.813**	0.254	-0.005
TA	**-0.814**	0.062	-0.193	**0.545**
Cu	**-0.625**	**0.718**	0.273	-0.140
Eigen value	**8.060**	**5.389**	**4.954**	**2.597**
Variability%	**38.381**	**25.661**	**23.591**	**12.368**
Cumulative%	**38.381**	**64.042**	**87.632**	**100.000**

For the data set pertaining to the MP sites, four PCs were obtained having eigen value >1 as depicted in screen plot for MP sites the (Figure-5). Among total four significant PCs (Table-4), PC1, explaining about 44.64% of the total variance, has strong positive loading on TP, Pb and moderate positive loadings on Cu, Zn, F^-, BOD and TA. These factors represent the contribution of excess localized anthropogenic input into water bodies, runoff from agricultural fields using phosphatic fertilisers and some industrial effluents. PC2, explaining about 29.63% of the total variance, has strong positive loading on, COD, NH_4-N and Cd and moderate loadings on NH_3-N and TA, which represent the direct input of organic matter and domestic wastewater containing chemicals that are susceptible to oxidation from the nearby cities. PC3, explaining about 15.25% of the total variance, has strong positive loading on Ni and, moderate loading on BOD. In these areas, farmers use the fertilizer, which represents point and non-point source pollution from orchard and agriculture areas. PC4, (10.47%) has moderate positive loadings on NH_4-N. The factor also represents the release of organic waste in to the river system.

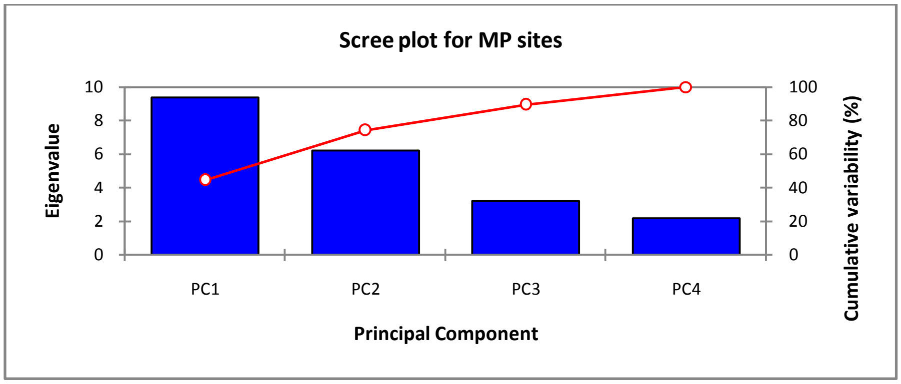

Figure-5 Screen plot for MP sites

Table-4. Principal Component Analysis of MP sites.

Variables	PC1	PC2	PC3	PC4
pH	**-0.845**	0.235	0.477	-0.057
DO	**-0.583**	0.498	-0.345	**-0.541**
BOD	**0.581**	0.414	**0.638**	-0.290
COD	0.386	**0.863**	-0.072	-0.319
NH_4-N	-0.088	**0.824**	0.120	**0.546**
NH_3-N	-0.476	**0.717**	0.502	0.084
NO_3-N	**-0.894**	0.375	-0.168	-0.179
NO_2- N	**-0.870**	0.449	-0.146	-0.145
TP	**0.894**	0.236	0.197	0.326
TKN	**-0.928**	0.183	0.241	0.218
TDS	**-0.833**	-0.002	0.257	0.490
TSS	0.057	0.338	**-0.810**	0.475
F^-	**0.729**	**0.566**	-0.234	0.304
Fe	-0.428	**0.823**	-0.021	0.372
Ni	-0.088	-0.256	**0.963**	-0.005
Cr	-0.680	**-0.556**	-0.460	-0.128
Zn	**0.741**	**-0.640**	-0.062	0.193
Cd	0.005	**0.888**	-0.293	-0.355
Pb	**0.969**	0.196	0.025	-0.145
TA	**0.721**	**0.631**	-0.016	0.286
Cu	**0.702**	0.507	0.153	-0.476
Eigen value	**9.374**	**6.222**	**3.203**	**2.200**
Variability%	**44.640**	**29.630**	**15.252**	**10.478**
Cumulative%	**44.640**	**74.270**	**89.522**	**100.000**

Lastly, for the data set pertaining to water quality in HP site, two PCs were obtained having eigen value >1 as shown in the scree plot for HP sites (Figure-6). Among the two PCs (Table- 5) , PC1 explaining 67.77% of total variance, has strong loadings on pH, BOD, COD, NH_3-N, NO_3-N, NO_2-N, TKN, TP, TDS, F^-, Ni and Cd. This factor can be interpreted as untreated wastewater and sewage disposal from both Sambalpur and Cuttack cities and also industrial effluents. The strong negative loading on DO in PC1, is due to anaerobic conditions in river from the loading of high dissolved organic matter. PC2, explaining 32.22% of the total variance, has strong positive loadings on TSS and Pb, and moderate positive loading on Zn and Cu. These factors also represent pollution from domestic wastewater and non-point sources. Through the PCA, the sources of the pollutants were identified in the three zones. As mentioned above, it can be helpful to the government and managers, who can lay down different regulations and policies in three zones respectively.

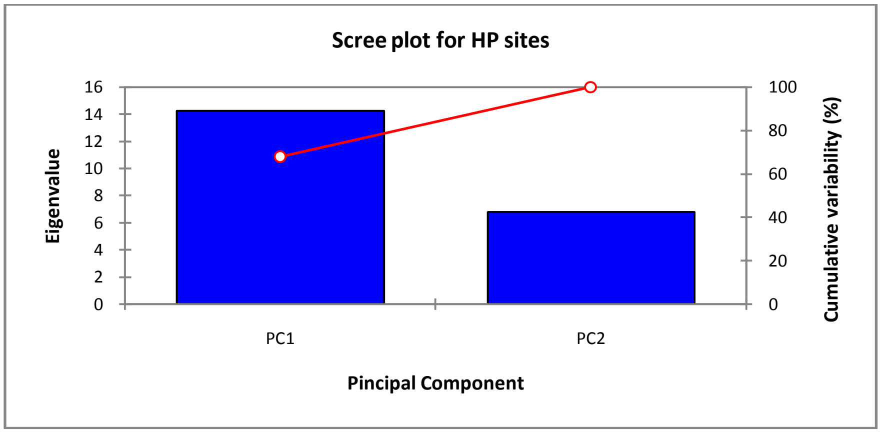

Figure-6 screen plot for HP sites

Table-5. Principal Component Analysis of HP sites

Variables	PC1	PC2
pH	**-0.871**	-0.491
DO	**-0.952**	0.307
BOD	**0.932**	0.363
COD	**0.931**	0.364
NH_4-N	-0.394	-0.919
NH_3-N	**0.998**	-0.069
NO_3-N	**0.999**	0.053
NO_2- N	**1.000**	0.001
TP	**0.965**	-0.261
TKN	**0.916**	-0.401
TDS	**0.774**	**-0.633**
TSS	-0.081	**0.997**
F^-	**0.996**	-0.087
Fe	**-0.793**	-0.609
Ni	**1.000**	-0.022
Cr	**-0.734**	-0.680
Zn	**-0.742**	**0.671**
Cd	**0.829**	**-0.559**
Pb	0.168	**0.986**
TA	-0.506	**-0.863**
Cu	**-0.791**	**0.611**
Eigen Value	**14.231**	**6.768**
Variability%	**67.771**	**32.229**
Cumulative%	**67.771**	**100.000**

APPLICATIONS

The application of multivariate statistical analysis is an excellent technique for assessment of large and complex databases, generated by continuous monitoring of water quality to evaluate similarity and dissimilarity in the physicochemical characteristic of surface water bodies. These methods can also be used to discern water quality variables responsible for seasonal variation among them and to categorise them on the basis of pollution levels besides identifying the source of pollution. Thus these techniques are believed to be valuable for water resource managers to design sampling, analytical protocols and the effective measures to control / management of pollution load in the surface water.

CONCLUSIONS

In this case study, different multivariate statistical techniques were used to evaluate spatial variations in surface water quality of the Mahanadi river basin. Hierarchical cluster analysis grouped 13 sampling sites into three clusters of similar water quality characteristics. Based on obtained information, it is possible to design an optimal sampling strategy, which could reduce the number of sampling stations and associate costs. Also this analysis allowed the identification of four different zones for LP and MP and two distinct zones for HP in the river, with different water quality. Although the factor/principal component analysis did not result in a significant data reduction, it helped extract and identify the factors/sources responsible for variations in river water quality at three zones. The major pollutants in all the three zones are contributed by local anthropogenic activities rather than agricultural/ land drainage. The intensity of microbial activities and the influx of organic sewage are reflected through the high BOD, NH_3-N, NO_3-N, NO_2-N, TKN values for cluster-III in HP, which are more than the permissible limit for drinking water. The inverse relationship between DO with BOD and DO with TKN and TP in HP sites implies that the organic nitrogen part plays a major role in the depletion of DO in the river systems. The PCs obtained from principal component analysis indicate that parameters responsible for water quality variations are mainly related to untreated or partially treated municipal sewage, domestic and industrial wastewater. With serious situation of water pollution in the Mahanadi watershed, the management of water quality of the different zones is becoming more and more important as well as the planning of the whole watershed. According to the sources of pollution, different measures should be adopted, in order to control the total quantity of the pollutants and achieve the goal of sustainable use of the water resources. It could be helpful to managers and government agencies in water quality management. As a result, multivariate statistical methods including factor, principal component, and cluster analysis can be used to understand complex nature of water quality issues and determine priorities to improve water quality.

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