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A Statistical Study of Water Quality of River Brahmani, Odisha (India) To Assess Its Potability

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Abstract: The surface water quality of Brahmani river system in Odisha was analyzed by applying the multivariate statistical techniques including cluster analysis (CA), factor analysis (FA) and principal component analysis (PCA). Agglomerative hierarchical cluster analysis (AHC) grouped 15 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 eight PCs for LP and two PCs for MP sites while two PCs were obtained for HP sites with each cases having Eigen values (Component variance values) >1. The PCs obtained from factor analysis indicates that the increase in load of nitrate,Fe, Turbidity, Calcium, Sulphate, Fluorine, Alkalinity, Boron, Magnesium 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: Brahmani River, Industrial/Urban sewage, Cluster analysis, Principal Component analysis, Statistical analysis, Water quality.

I. INTRODUCTION

Water, a prime natural resource, is a basic need for sustenance of human civilization. Sustainable management of water resources is an essential requirement for the growth of the state's economy and well being of the population. As per National water policy, 2002, water resources development and management will have to be planned for a hydrological unit such as drainage basin as a whole or for a sub-basin for sustainable use incorporating quantity and quality aspects as well as environmental considerations.

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 industrialization and urban sprawl. Anthropogenic influences such as urbanization, 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. The application of different multivariate statistical techniques, such as cluster analysis (CA) , principal component analysis (PCA) 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. 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 Brahmani watershed is the most developed and urbanized 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 14 years monitoring program (2000 to 2014) 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
- Classify the watershed into several zones with different water quality.
- Extract and establish the parameters that are most important in assessing variation in water quality of different zones,
- 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.
- To perform time series analysis, trend Analysis and PCA Analysis of water quality parameters.
- To interpret the complex water quality data matrices as well as to identify the possible sources or factors that influences the water quality by using different analysis methods viz., principal Component Analysis (PCA) and Cluster Analysis (CA).
- To compare all the employed models in terms of the predictive ability as well as to carry out the analysis of the estimated water quality parameters so as to obtain the most suitable model.

II. REVIEW OF LITERATURE

Water quality is a complex subject, which involves physical, chemical, hydrological and biological characteristics of water and their complex and delicate relations. From the user's point of view, the term "water quality" is defined as "those physical, chemical or biological characteristics of water by which the user evaluates the acceptability of water". For example for drinking water should be pure, wholesome, and potable. Similarly, for irrigation dissolved solids and toxicants are important, for outdoor bathing pathogens are important and water quality is controlled accordingly.

Dugan [1972] suggested that all biological reactions occur in water and it is the integrated system of biological metabolic reactions in an aqueous solution that is essential for the maintenance of life. **Pani [1986]** in his study realized that due to increasing industrialization on one hand and exploding population on the other, the demands of water supply have been increasing tremendously. Moreover considerable part of this limited quality of water is polluted by sewage, industrial waste and a wide range of synthetic chemicals. Heavy metal are considered as major environmental pollutants and regarded to be Cytotoxic, Mutagenic, and Carcinogenic. The Heavy Metal pollution of natural environment has been consistently increasing through effluents, sedimentation of rocks and mining activities **(Manjit [1988])**. **Priti Singh et.al [2005]** assess and map the spatial distribution of surface water quality of the Mahanadi, Odisha by using GIS.APHA's standard laboratory procedure has been adopted to assess the quality of ground water. The spatial distribution map of pH, Chlorides, Magnesium and sulphate shows that, these parameters are within range as per standard. **Samantray et al.** were studied the water quality of Mahanadi and its distributaries rivers, streams, Atharabanki river and Taldanda Canal adjoining Paradeep in three different seasons namely summer, pre-monsoon and winter..Their findings highlighted the deterioration of water quality in the rivers due to industrialization and human activities **(Samantray et al., 2006).Kamal [2007]** carried out on physicochemical parameter of river water affects the biological characteristics and indicates the status of water quality. Different types of Physicochemical parameters of water are pH, DO, BOD, COD, Chloride, TDS, Nitrate, Sulphates, TH, EC and Fluoride. These parameters are solely responsible for water quality. **Adetunde et.al [2007]** have studied the area and investigated physicochemical and bacteriological qualities of surface water in the north areas and south local government areas of State, Odisha. Water samples were collected from different areas of North and South local areas. **SwarnaLatha [2008].** The desirable limit of TDS is 500 mg/l. If TDS value is more than 500 mg/l, it may cause gastro intestinal irritation. High TDS presence in the water decreases the quality and affects the taste of water as found from **Guru Prasad, 2005.Sayyed et.al [2009]** assessed the surface water from the south-eastern part of Odisha city for the seasonal variation in their quality parameters. Using Piper diagram the hydrogeochemicalfacies were identified and the surface waters were classified with regards to the changes in their major chemical compositions. **Shimaa M. Ghoraba et.al [2008]** collected many ground water samples from different districts of Mahanadi,Odisha. The groundwater recorded a wide range in TDS. Chloride is one of the most important parameter in assessing the water quality and higher concentration of chloride indicates higher degree of organic pollution **(Yogendra andPuttaiah, 2008).Khare et.al [2010]** carried out on water quality assessment of Mahanadi, Sambalpur. He was done water analysis for the parameters like pH, DO, BOD, COD, TDS, calcium, Magnesium and Hardness for lake water. **Venkatesharaju*et al*., [2010]** signifieswater recourses have critical importance to both natural and human development. It is essential for agriculture, industry and human existence. Water is one of the most abundant compounds of the ecosystem. **Mona A. Hagras et.al [2011]** assessed the quality of groundwater and to characterize the hydrochemical characteristics of the surface water in Odisha, surface water samples were collected from different cities of Odisha analyzed for 15 water quality parameters. **Lohani et.al [2011]** depicts drinking water quality management through various physicochemical parameters and health hazard problems with their remedial measures in Bhubaneswar city of Odisha. **Sahu[2015]** describes the effect of poor water quality on human health was noted for the first time in 1854 by John Snow, when he traced the outbreak of cholera epidemic in London to the Thames river water which was grossly polluted with raw sewage. **Rout [2016]** carried out an analysis was carried out by taking certain important parameters like pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), Chloride, total dissolved oxygen (TDS), Nitrate, sulphates, total hardness (TH), electrical conductivity (EC) and Fluoride. **Vega et al., [2016]**signifies the application of different multivariate statistical techniques, such as cluster analysis (CA), principal component analysis (PCA) helps in the interpretation of complex data matrices to better understand the water quality and ecological status of the studied systems.

III. STUDY AREA AND DATA COLLECTION

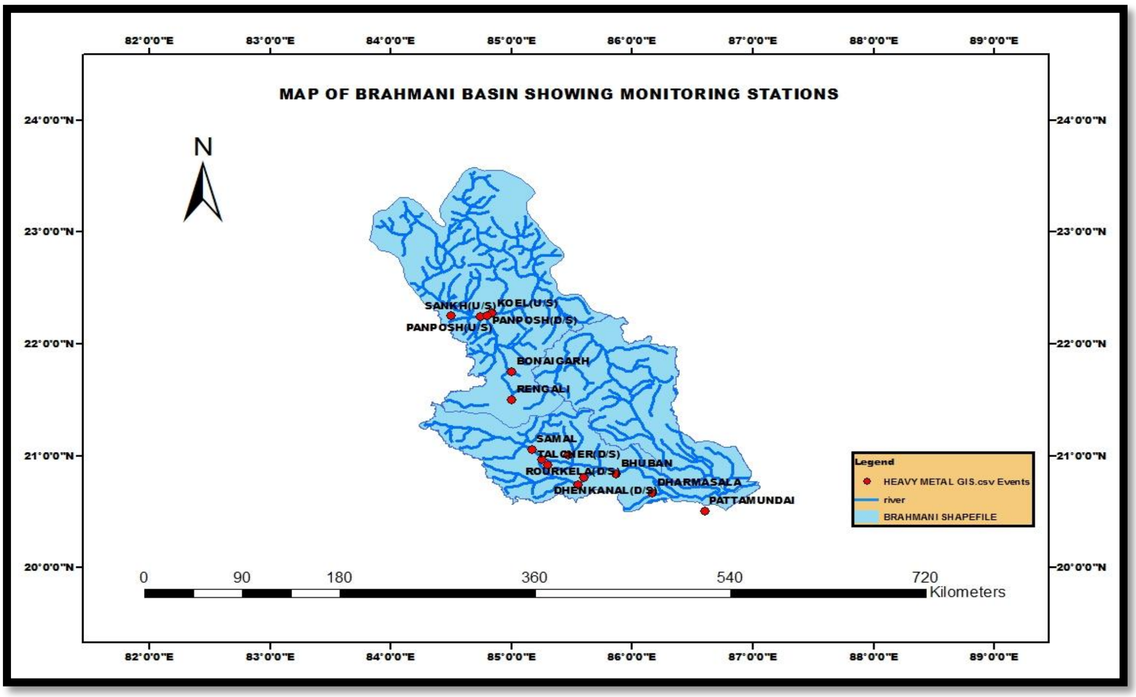
STUDY SITE:

Brahmani, the second major river in Odisha, is formed by the combined waters of South Koel and Sankh rivers at Vedvyasa near Rourkela in the Sundergarh district. The left bank tributary South Koel originates near Nagri village in the Ranchi district of Jharkhand state. After its confluence with river Karo in Singhbhum district, it is known as koel. From Manoharpur, it flows in the south-west direction for a distance of about 54 km uptoVedvyasa where the right bank tributary Sankh joins with it. River Sankh originates an elevation of 1000 m near village Lupungpat in Ranchi district of Jharkhand state.

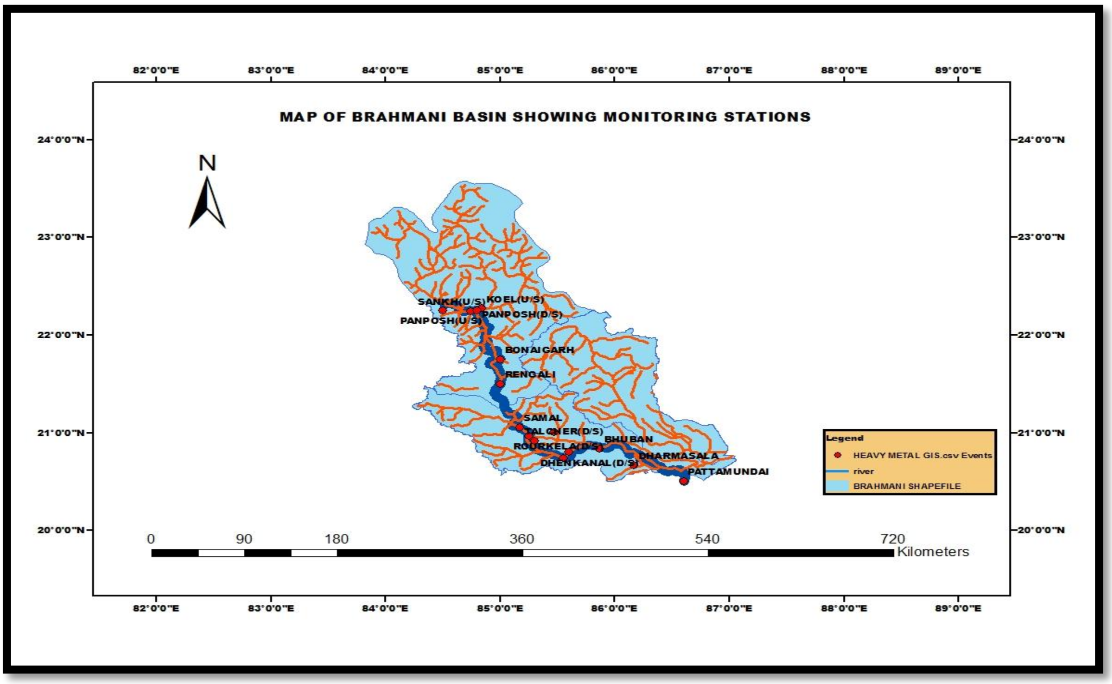
River Brahmani travels southward through valleys incised in the Gadjat Hills to form the famous Gangpur Basin. In this stretch the river is joined by several fast flowing tributaries. The deltaic region of Brahmani starts from Jenapur at river distance equals to 315 km, where the Kalamitra Island divides the river into two branches. The left branch is called Brahmani main and the right branch is called Kharasuan, which agains join the Brahmani river at RD 429 km. River Birupa, a distributary of Mahanadi river, joins Brahmani river at RD 327 km. In place of being a receiving stream, it now branches into numerous spill channels which criss-cross the spill channels of river Baitarani and ultimately joins river Baitarani at RD 446 km to form Dhamra mouth before finally being dischargedinto Bay of Bengal at RD 461 km.

The basin area of river Brahmani in Odisha constitutes 57.63% of the total basin area. The basin covers 9 revenue districts of the State.

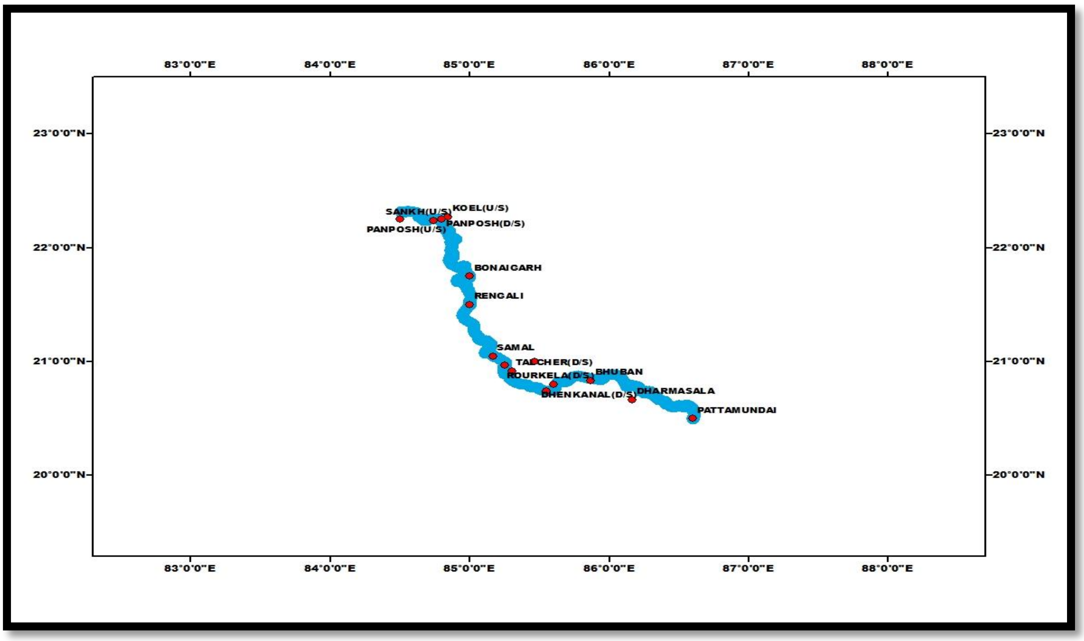
The below (figure 1, 2 & 3) showing monitoring stations of Brahmani basin by the application of GIS Software.



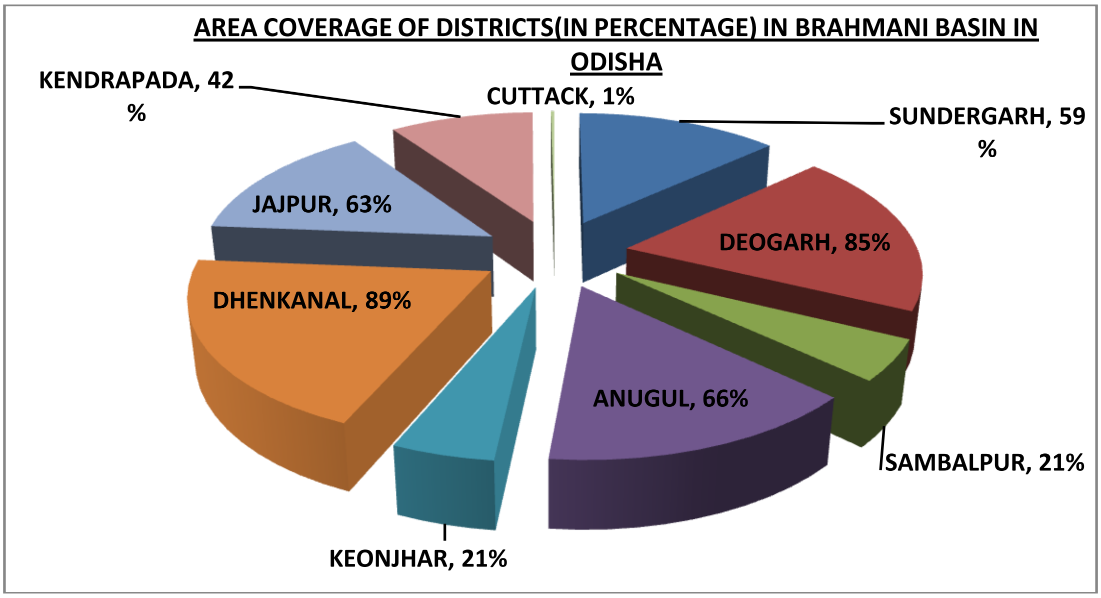
(Figure1.Brahmani basin showing fifteen monitoring stations)



(Figure2. Flow path of Brahmani basin showing monitoring stations)



(Figure3.Brahmani basin showing flow path accompanied with monitoring stations)



(Figure4. Area coverage of districts of Brahmani basin in Odisha)

Fifteen different stations as mentioned below are selected across the stretch of the Brahmani River. The selection of the sites was done depending upon the industrial and mining activities along the river bank (Table 1)

Table1.Showing the monitoring stations and the justification on the site selected

SL NO	MONITORING STATION	JUSTIFICATION ON THE SITE SELECTED
1	SANKHA(U/S)	D/S of Mandira dam
2	KOEL(U/S)	Before confluence with river sankha and after waste water discharge of koelnagar
3	PANPOSH(U/S)	Water quality before industrial activity after confluence of Sankh and Koel
4	PANPOSH(D/S)	Impact of industrial activities like RSP and domestic waste water discharge from Rourkela city.
5	ROURKELA(D/S)	To asses water quality improvement at further down stream of Rourkela city and identification of polluted stretch.
6	BONAIGARH	To assess the improvement of water quality.
7	RENGALI	A multipurpose dam
8	SAMAL	Samal Barrage, Water intake point for TSTPP,Kaniha
9	TALCHER(U/S)	Water intake point of industries and mines
10	TALCHER(D/S)	Impact of industrial and muncipal discharge. Downstream of the confluence of Nandirajhor with Brahmani
11	DHENKANAL(U/S)	Upstream of Dhenkhanal town
12	DHENKANAL(D/S)	Downstream of Dhenkhanal town
13	BHUBAN	A major human settlement with water intake point
14	DHARMASALA	Thickly populated area with intensive agriculture practice D/s of industrial activities at Kalinganagar
15	PATTAMUNDAI	Thickly populated area, Tidal effect

IV. MATERIALS AND METHODS

SAMPLING AND PARAMETERS: Water samples were collected from 15 stations along the course of theBrahmani river system, starting from the Sankh U/s Reservoir to Pattamundai. The sampling strategy was designed in such a way to cover a wide range of determinants at keysites 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 analyzed yearly from 2000 to 2015. The mean value of the data sets was taken into consideration for evaluating the pollution load in the water system. The measured parameters include pH, Nitrate(NO_3),Total Dissolved Solids (TDS), Boron, Alkalinity, Calcium, Magnesium, Turbidity, Chloride(Cl^-) , Sulphate (SO_4^{2-}), Fluoride(F^-) and Iron(Fe).

(Table 2.MINIMUM, MAXIMUM, MEAN AND STANDARD DEVIATION OF WATER QUALITY PARAMETERSAT DIFFERENT MONITORING STATIONS FROM 2000 TO 2014)

PARAMETERS	STATIONS	MIN	MAX	MEAN	STANDARD DEVIATION
PH	15	7.478	7.821	7.681933	0.093202136
TURBIDITY	15	61.625	164.3	93.48833	24.89554116
TDS	15	71.66667	234.1667	111.0889	46.27446293
CALCIUM	15	12.29	30.06	16.78933	5.76978146
MAGNESIUM	15	4.1325	11.50167	6.102334	2.419139123
IRON	15	1.323833	5.828917	2.858724	0.995811285
CHLORINE	15	9.1	28.01	13.82713	5.609048963
FLUORINE	15	0.21075	1.593833	0.494911	0.428257389
NITRATE	15	1.705833	30.365	4.184667	7.263498
SULPHATE	15	7.138	37.55	14.71427	10.31852366
ALKALINITY	15	36.885	75.06333	48.48828	12.9094684
BOR0N	15	0.033333	0.178333	0.076278	0.038847244

STASTICAL ANALYSIS: In recent years, various statistical procedures based on multivariate data taken fromriver system have been used to formulate environmental classifications, which help for a better understanding of the chemical processes occurring in the river environment. Principal component analysis and cluster analyses (CA) were carried out for data set obtained yearly from 2000-2014. The factor analyses were calculated using component variance values greater than 1.0 is considered the significant influences towards the geo-chemical processes.The hierarchical clustering was carried out from data normalized to a zero mean and using Euclidian distances as a measure of similarity. Ward's method was selected because it possesses a small space-distorting effect and accesses more information on cluster content. The results indicate that the CAtechnique offers a reliable classification of surface water in the whole region and make it possible to design a future spatial sampling strategy in an optimal method that can reduce the number of monitoring sites.

CLUSTER ANALYSIS:

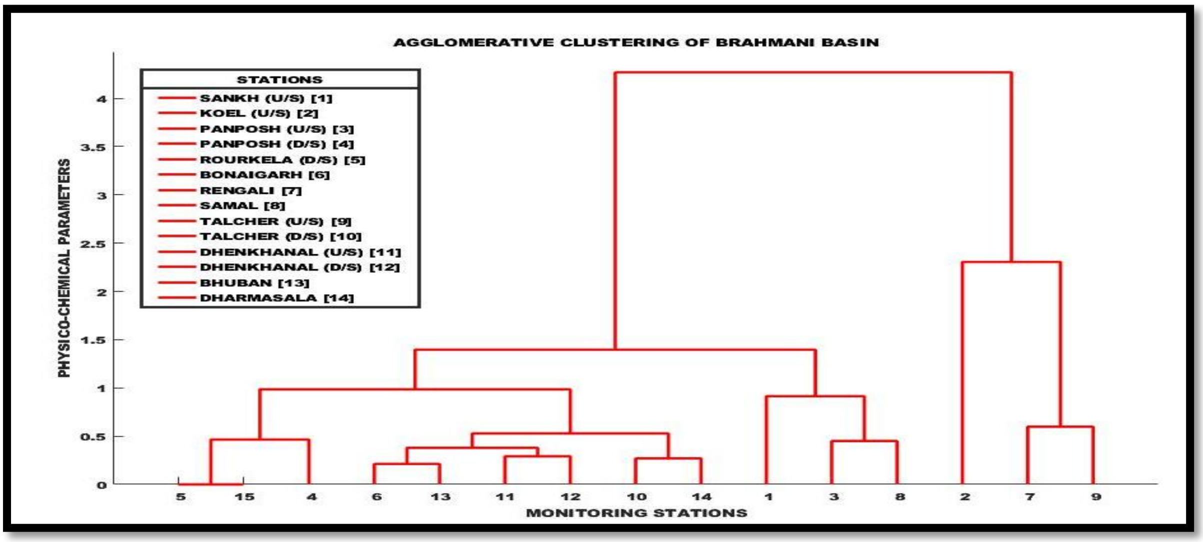
Cluster analysis (CA) is used to develop meaningful aggregations or groups of entitiesbased on a large number of interdependent variables. The resulting clusters of objects should exhibit high internal (within-cluster) homogeneity and high external (between clusters) heterogeneity. Of all cluster analysis, 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.

PRINCIPAL COMPONENT ANALYSIS / FACTOR ANALYSIS:

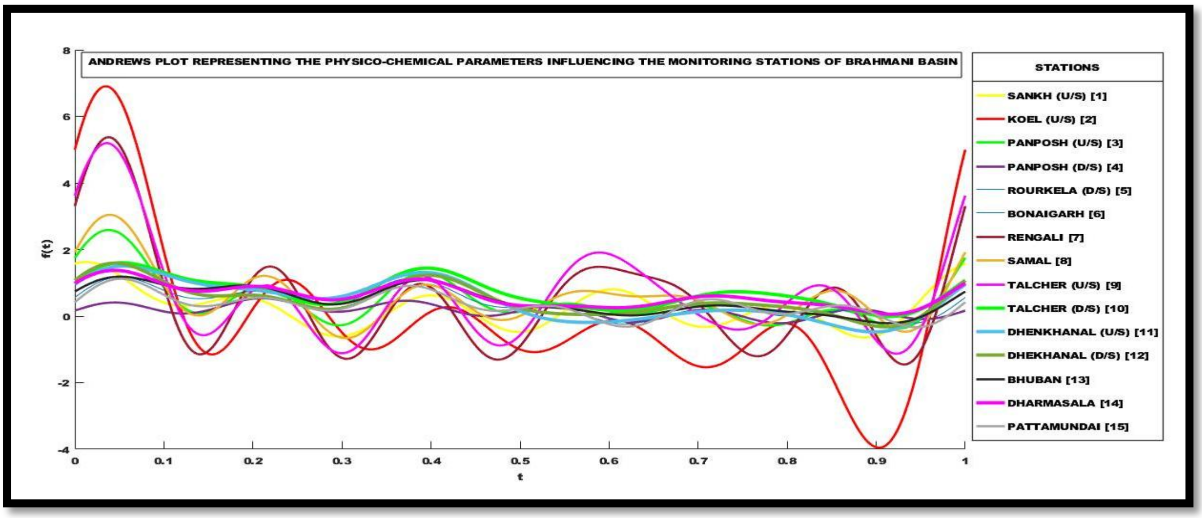
Factor analysis, which includes PCA is a very powerfultechnique applied to reduce the dimensionality of a dataset consisting of a large number of interrelated variables, while retaining as much as possible the variability presented in dataset. Mathematically, the PCs are computed from covariance or other cross-product matrix, which describes the dispersion of the multiple measured parameters to obtain Eigen values (Component variance values) and eigenvectors. Factor analysis attempts to explain the correlations between the observations in terms of the underlying factors, which are not directly observable. This study comprises application of multivariate statistical techniques to analyze water quality dataset obtained from the Mahanadi River in Odisha.

V. RESULTS AND DISCUSSION:

SPATIAL SIMILARITIES AND SITE GROUPING:In this study, sampling sites classification was performed by theuse of cluster analysis. The relationships among the stations were obtained through cluster analyses usingWard'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 numberof clusters was also decided by water environment quality, which is mainly effected by land use and industrial structure.The physicochemical parameters likepH, Nitrate(NO_3),Total Dissolved Solids (TDS), Boron, Alkalinity, Calcium, Magnesium, Turbidity , Chloride(Cl^-) , Sulphate (SO_4^{2-}), Fluoride(F^-) and Iron(Fe)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 16 monitoringstations 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.



(Figure5. Dendrogram showing clustering of monitoring sites according to surface water qualitycharacteristics of the Brahmani river basin)



(Figure6.Andrew plots showing physico-chemical parameters and their composition of monitoring sites of the Brahmani river basin)

CLUSTER- I (4-5-6-10-11-12-13-14-15): Monitoring sites, mainly located in between the Panposh (U/s) uptoPattamundai including Rourkela, Bonaigarh, Talcher, Dhenkanal (U/s), Dhenkanal (D/s), Bhuban namely (stations4-5-6-10-11-12-13-14-15) 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 (1-3-8): This cluster sites mainly located in between Sankh U/s uptoSamal including Panposh U/s namely (stations1-3-8).These sites are classified as moderately polluted (MP).
From the data, it is seen that there is deterioration of water quality at Panposh D/s and Talcher D/s. This is an expected observation since a number of large and medium industries and mines are operating at Rourkela and AngulTalcher industrial complex.

The spatial variation of water quality is in a predictable way. By the time the river reaches Bonaigarh there is a significant improvement in water quality, which remain more or less the same up to Talcher U/s through Rengali and Samal, since there is no major urban settlements or waste water outfalls in this stretch.

After confluence of Nandira River with Brahmani River, the water quality at Talcher D/s deteriorates both with respect to Hg and Cd. Though As value increases in comparison to U/s stations of Talcher still it remains within the prescribed limit where both Pb and Ni counts significantly exceeds the prescribed limit. The water quality gets improved uptoDhenkanal U/s. Impact of Dhenkanal town on the water quality of Brahmani River is not that much significant irrespective of increase in Cd and Fe counts.

After Bhuban, there is some restoration in the water quality which continues uptoPottamundai through Dharmasala. The magnitude of improvement in the water quality in this stretch is however not the same as that in the Bonaigarh-Rengali-Samal stretch, since there is increase in the population density and intensity in agricultural activities as the river enters into the deltaic region.

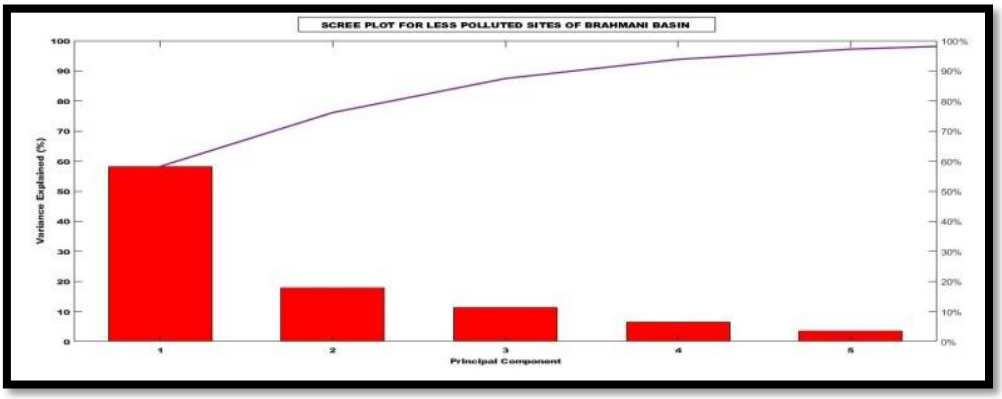
CLUSTER- III (7-9):This cluster mainly includes Rengali and Talcher U/s. These sites are classified as highly polluted (HP). During the eighties and early nineties, the water quality of the river at Rourkela and Angul-Talcher caused much concern. Presently, however, there is no indication of any severe industrial pollution in these two stretches. This could be because of some effective control measures taken by the industries and mines, subsequently. A significant step in this direction is recycling/reusing of waste water by some of the major polluting units and reduction in the quantity of effluent generation by some large industries. Improvement in the water quality over the years is reflected in the water quality trend at Talcher D/s and the rivulet Nandira. This small tributary of Brahmani originates at Golabandha and after travelling a distance of about 39 km, joins Brahmani at kamalnaga. Most of the major industries and mines in the Angul-Talcher area are located in the catchment of Nandira. Till late nineties, it is used to receive effluent (directly or indirectly) heavily laden with suspended solids and other pollutants, from many major industries. With improved pollution control measures and recycling of waste water, the quantum of effluent discharged to Nandira has now been reduced considerably, leading to a significant improvement in its water quality and hence at Talcher D/s.

DATA STRUCTURE DETERMINATION AND SOURCE IDENTIFICATION:

Principal component analysis/factor analysiswas 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 eight PCs for LP and two PCs for MP sites while two PCs were obtained for HP sites with each cases having eigen values (Component variance 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.

LESS POLLUTED SITES:

For the data set pertaining to LP sites, eight PCs were obtained having eigen value >1 as shown in the screen plot for LP sites. Among four PCs, PC1, explaining 58.1807% of the total variance, has moderate positive loadings on Calcium, Magnesium, Iron, TDS, Chlorine, Nitrate, Sulphate and Strong positive loading on pH, Fe, Turbidity and Alkalinity which is attributed to localized anthropogenic input and also due to deamination of nitrogen containing organic compounds rather than river runoffs**(Figure 7).** PC2, explaining 17.911% of the total variance, moderate positive loadings on Chlorine, Nitrate, and strong positive loadings on Fe, Boron, Sulphate, Fluorine and strong negative loading on Mg, Ca and Turbidity..



(Figure7. Scree plot for LP Sites)

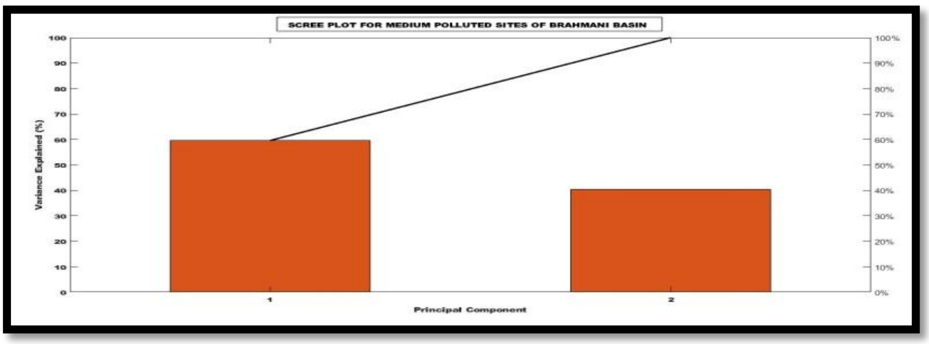
PC3, explaining 11.3262% of the total variance, has strong positive loadings on pH, Turbidity, strong negative loading on Chlorine, Alkalinity and Nitrate, moderate positive loading on Sulphate, Fluorine and TDS. PC2 and PC3 represent organic pollution from domestic waste and non-point source pollution. PC4, explaining the lowest variance (6.3741%) has moderate loadings on Fe, Calcium and Nitrate and strong positive loading on pH, Alkalinity which is due to normal biological degradation products of nitrogenous organic matter and the process is repeated for rest of the PCs of less polluted sites.

Table No.3Principal Component Analysis of LP sites

PARAMETERS	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
PH	0.0663	-0.0006	0.0626	0.139	0.0711	0.024	0.0806	0.0748
TURBIDITY	0.0334	-0.0123	0.0403	-0.0833	0.0111	0.0439	0.0003	0.0622
TDS	0.0121	0.0081	0.003	0.0044	0.0152	-0.0103	-0.0165	0.0002
CALCIUM	0.0142	-0.0103	-0.0052	0.0018	0.0003	0.025	-0.0054	-0.0208
MAGNESIUM	0.0174	-0.0017	-0.0005	0.0035	-0.0372	-0.0162	-0.0005	0.0135
IRON	0.0452	0.0366	-0.0501	0.0062	-0.0335	0.021	0.0236	-0.0555
CHLORINE	0.018	0.0091	-0.0065	-0.0217	0.018	-0.0229	0.0267	-0.0142
FLUORINE	-0.0022	0.0212	0.0025	0.0009	0.0002	0.0074	-0.0113	0.0049
NITRATE	0.0015	0.0002	-0.0069	0.0003	0.0011	0.0016	0.0003	0.0025
SULPHATE	0.0071	0.0143	-0.008	-0.0023	-0.0062	0.0013	0.0008	-0.0023
ALKALINITY	0.0244	-0.0091	-0.0048	0.0117	-0.006	0.0046	0.0048	0.0112
BOR0N	-0.0258	0.0274	-0.0012	0.0039	-0.0042	0.0219	0.0432	0.0067
COMPONENT VARIANCES	6.9817	2.1493	1.3591	0.7649	0.4075	0.2164	0.1211	0
PERCENT VARIANCE EXPLAINED	58.1807	17.9112	11.3262	6.3741	3.3955	1.8034	1.0089	0

MEDIUM POLLUTED SITES

For the data set pertaining to the MP sites, two PCs were obtained having eigen value >1 as depicted in screen plot for MP sites. Among total seven significant PCs, PC1, explaining about 59.5965% of the total variance, has strong positive loading on pH, Fe, Sulphate, Turbidity and moderate positive loadings on TDS, Magnesium and Fluorine**(Figure8).**These factors represent the contribution of excess localized anthropogenic input into water bodies, runoff from agricultural fields using phosphatic fertilizers and some industrial effluents. PC2, explaining about 40.4035% of the total variance, has strong positive loading on pH, TDS, Sulphur, Fluorine, Boron and moderate loadings on Mg and Alkalinity which represent the direct input of organic matter and domestic wastewater containing chemicals that are susceptible to oxidation from the nearby cities.



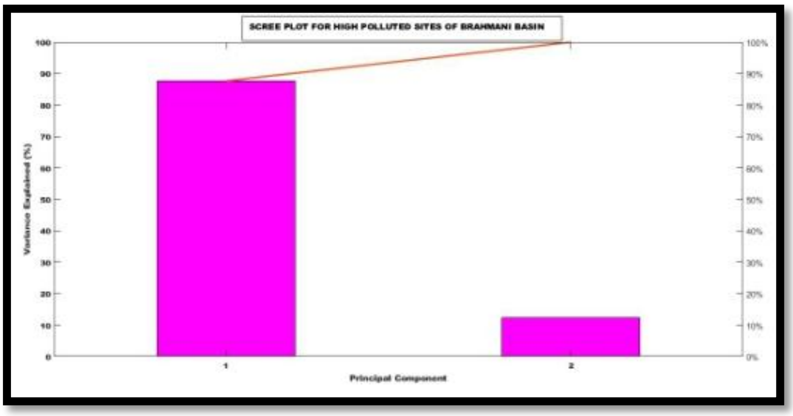
(Figure 8.Scree plot for MP Sites)

Table No.4Principal Component Analysis of MP sites

PARAMETERS	PC1	PC2
PH	0.0759	0.0562
TURBIDITY	0.0431	-0.0344
TDS	0.0014	0.0302
CALCIUM	-0.0116	0.0457
MAGNESIUM	0.0176	0.004
IRON	0.0349	-0.0175
CHLORINE	0.0076	-0.0135
FLUORINE	0.0191	0.0282
NITRATE	0.0106	-0.0076
SULPHATE	0.0636	0.0661
ALKALINITY	-0.0461	0.0048
BOR0N	0.0941	0.0613
COMPONENT VARIANCES	7.1516	4.8484
PERCENT VARIANCE EXPLAINED	59.5965	40.4035

HEAVY POLLUTED SITES:

Lastly, for the data set pertaining to water quality in HP sites, two PCs were obtained having eigen value >1 as shown in the scree plot for HP sites. Among the one PCs, PC1 explaining 87.6845% of total variance, has strong loadings on Turbidity, Iron, Nitrate. This factor can be interpreted as untreated wastewater and sewage disposal from both Rengali and Talcher cities and also industrial effluents. The strong negative loading on NO_3 in PC1, is due to anaerobic conditions in river from the loading of high dissolved organic matter (Figure 5).



(Figure 9. Scree plot for HP Sites**)**

PC2 explaining about lowest variance of 12.3155% having strong positive loadings on Sulphate, Boron and moderate positive loadings on Turbidity, TDS, Calcium, Fluorine and strong negative loading on pH, Magnesium, Fluorine and Alkalinity. 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.

Table No 5. Principal Component Analysis of HP sites:

PARAMETERS	PC1	PC2
PH	-0.1437	-0.1208
TURBIDITY	0.1669	0.0576
TDS	0.0715	0.0135
CALCIUM	0.0439	0.0391
MAGNESIUM	0.0444	-0.0477
IRON	0.1332	-0.0645
CHLORINE	0.0572	0.0454
FLUORINE	0.0596	-0.0428

NITRATE	**0.1716**	**0.0053**
SULPHATE	**0.0396**	**0.1146**
ALKALINITY	**0.0317**	**-0.0491**
BOR0N	**-0.1098**	**0.1248**
COMPONENT VARIANCES	**10.5221**	**1.4779**
PERCENT VARIANCE EXPLAINED	**87.6845**	**12.3155**

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 yearly variation among them and to categorize 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.

VI. CONCLUSIONS

In this case study, ***multivariate statistical techniques*** were used to evaluate ***spatial variations in surface water quality of the Brahmani river basin***. Hierarchical cluster analysis grouped 15 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 three different zones for LP and MP and HP in the river, with different water quality. The major pollutants in all the three zones arecontributed 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 Turbidity, Iron, and Nitrate values for cluster-III in HP, which are more than the permissible limit for drinking water.The inverse relationship between Calcium with Sulphate and Boron with Fluorine and Alkalinity 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 fromprincipal 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 Brahmani 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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