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ORIGINAL ARTICLE

Surface water quality assessment of Rivers in South Gujarat, India by using Principal Component Analysis (PCA) and Cluster Analysis (CA)

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ABSTRACT

This research was conducted to formulate a model for the identification of the most representative water quality parameters and sampling site reduction for periodic long term water management. We have evaluated the water quality of rivers namely Damanganga and Kolak of Valsad district, South Gujarat, India, based on various physiochemical parameters such as pH, Electrical Conductivity, Color, Dissolved Oxygen, BOD, COD, TDS, Chloride, Residual free chlorine, Fluoride, Sulfate, Total ammoniacal nitrogen, Zinc, Iron and Boron. The sampling was done for a year at selected sampling sites of the river, generating a huge data matrix. This paper highlights how Cluster Analysis can be used to categorize river sampling sites according to their pollution load. Principle Component Analysis is used to summarize water quality data and find relationship patterns between various parameters to group variables into a much-reduced set of components. We have done statistical analyses with the help of SPSS software version 20. After site categorization and parameter reduction, we find that Kolak River has relatively less polluted water. It helped us to find out the exact type of pollutant at various points of the river and hence the changing aquatic floral diversity. The reduced parameters were pH, DO, COD, Total ammoniacal nitrogen, EC and Total Hardness. The study will guide government bodies in effective planning of restoring the river water quality.

Keyword: *Physicochemical parameters; Cluster Analysis; Principle Component Analysis; Surface water quality*

Abbreviations

PCA, Principal Component Analysis

EC, Electrical conductivity

DO, Dissolves oxygen

BOD, Biological oxygen demand

COD, Chemical oxygen demand

TDS, Total dissolved solid

CETP, Common Effluent Treatment Plant

KMO, Kaiser-Meyer-Olkin

CA, Cluster Analysis

INTRODUCTION

Due to rapid and unplanned industrialization and urbanization in the study sites, there is much degradation of the environment. Pollution of air, water, and soil causes a change in the composition from normal to something that is harmful to biodiversity. Pollution will cause a shift of species composition from specialist to generalist as they are able to survive in a degraded environment. Only those species which can survive in the altered composition of soil, air, and water will live and rest will go extinct. Anthropogenic stress factors such as habitat destruction and habitat fragmentation are leading to an increased rate of extinction of species throughout the study sites. Many species of animal has become extinct in wild and many plants have been extinct from the earth. Human interferences adversely affect slow growing and slow-moving species of plant and animals. Among all form of pollution, water pollution will severely affect all form of life on earth. Water supports life on land as well as it is home to many plants and animals. So pollution of water will affect not only the terrestrial but also the aquatic ecosystem. Aquatic life includes both marines as well as freshwater ecosystem both of which are affected by water pollution. Nutrient and pollutant level in aquatic ecosystem determines its floral and faunal diversity. Toxic pollutants accumulate in the water and alter the species composition of an ecosystem (Woodwell G M., 1970). Toxicants persist for a long time in a perennial plant than an annual herb or shrub (Anderson et al., 1999). Apart from that, change in pH increases or decreases the availability of heavy metals causing by binding to certain ions and making them unavailable to plants (Barceló et al., 1990). Even nutrients when present in excess as in eutrophication, destroys the balance in the ecosystem. High water demand due to rapid urbanization and industrialization leads to increased water overuse and degradation (Idrissa Kabore., 2018).

Our rivers were vulnerable to pollution since industrialization. Water quality is an environmental issue in most developing countries. Degradation of water quality depends upon the land use pattern of the watershed area. There is much awareness about the sustainable management of water and its resources but effective tool for biomonitoring is limited (Idrissa Kabore et al., 2018). Due to temporal and spatial variation in water quality, there is a need for representative variables and reduction in the number of sampling sites. Principle Component analysis technique is used to interpret data as well as to recognize the pattern of water quality along the course of the river (Alberto et al., 2001). Multivariate techniques like Principle Component analysis used by Wang et al., 2013; Zhang et al., 2009 and Cluster Analysis used by Zhou et al., 2007 for data analysis. This study uses the exploratory analysis as was done by earlier works of Vega et al., 1998. PCA is performed by SPSS using factor analysis menu, however, it can also be done using Analyze or Data reduction menu selections also. PCA was also used to reduce the number of parameters and use the most significant dominant parameters for future studies (Parinet et al., 2004; Boyacioglu, H., 2006). In our study, we surveyed the flora along the course of the river and also determined some water quality parameters that affect biodiversity. Spatial variance of water quality can be observed due to pollution from the anthropogenic origin and temporal variance was observed due to seasonal and climatic cause affecting the quality of river water according to which various sites have been differentiated (Vega et al., 1998). The main objective of our study is – (1) zonation of river according to their level of pollution and reduce the number of sampling sites based on the study, (2) Extract the most representative parameters to be used for long term monitoring, (3) Identify the nature of pollution in each site so that we can take site-specific remedial measures, (4) Find out the parameters that exhibit seasonal and spatial variation, (5) Thus optimize water monitoring network.

MATERIAL AND METHOD

Study area

Our study area Valsad district lies at 20^0 37'N and 72^0 55' E in Gujarat, India covering an area of 2,947 km^2. It has six talukas through which several perennial rivers flow namely Damanganga, Par, Auranga, Kolak, Taan, Maan, Saasu, and Kothar. Two rivers – Kolak and Damanganga River were studied at various points (as shown in figure 1) for study and monitoring. Study sites were determined after considering the criteria of a physiochemical characteristic of water, hydro morphological characteristics, land use pattern, the extensive manual survey of the area, the study of published papers and annual reports of Gujarat Ecological Commission and own judgment. The reference site was taken as the areas immediately downstream of the river origin as these sites should be relatively less disturbed and should have the expected biological characteristic. Site suitable for study varies considerably from a reference site (Idrissa Kabore., 2018). In the present study, we have integrated several physiochemical parameters to determine the water quality of the river at various points in the upper, middle and lower reaches. Upper reach sampling site was the area downstream of river origin, middle reach sampling site was in the middle course of the river and lower reach sampling point was upstream from the river mouth. As these days no area is left pristine and all ecosystems are disturbed by human interferences we have to choose a relatively less disturbed site such as both the rivers in their upper reach as our reference site.

Description of the two rivers

Kolak River has an origin in the Saputara hills, India and has a length of 50 km, flows to the Arabian Sea. Upstream area of Kolak River at site Salvav village (1A) is hilly with dry deciduous forest. Kolak River is facing an agricultural runoff in upper reaches; water pollution from washing, domestic sewage and animal bathing in the middle reach at Tukawara village (1B); industrial effluent from small-scale industries dumped in the lower reaches at Vatar village (1C).

Damanganga River originates from Sahyadri hills of Western Ghats and flows to the Arabian Sea. A major part of this river lies in Maharashtra; it also flows through the Valsad district of Gujarat reaching Daman before joining the Arabian sea. We have a hilly terrain with dry deciduous forest in the upper reach of Damanganga River. River is facing an agricultural runoff in upper reaches at Chanod village (2A); brick kiln runoff, stone quarrying and industrial effluent from CETP are polluting the river in middle reaches of Namdah village site (2B) and industrial effluent and bridge construction in the lower reaches added pollution load at Zari village site (2C). Heavy sedimentation is observed at the river mouth. Damanganga

Stress factors affecting both rivers under consideration were industrialization, urbanization, agricultural runoff, pollution from livestock and damming of the river at several points. These rivers have both point and non-point source of pollution from domestic and industrial sources. All these factors are uncontrollable due to a population explosion in developing countries. Repeated damming is needed due to water scarcity but damming disturbs water flow and sediment flow hence alters the ecology (Idrissa Kabore et al., 2018). Furthermore, deposition of untreatable wastes from industries and Common Effluent Treatment Plant (CETP) in the lower reaches will affect the mangrove density and diversity at the mouth of the river. Thus monitoring of river water and using statistical analysis to formulate a model is very essential.

Floral diversity of rivers

There is a gradual change in the species composition along the course of the river, which is quite natural. According to the River Continuum Concept, a river is an open ecosystem as it has continuous interaction with the banks, as it moves from the headwater to the mouth of the river, thus causing a continuous alteration in the species composition.

Kolak River in its upper reach riverine region has agricultural vegetation and teak mixed forest in nonagricultural area and ferns only by the riverside. In the middle region, it has a mixed plantation of mango and chikoo bordered with teaks and casuarinas in a row while many species of grass in the immediate riverine region. Lower reach has *Casuarina* plantation and mangroves in the river mouth. This river and its tributaries had rooted macrophytes in its upper reach while at lower reach it has floating Eichhornia indicating pollution. At all sites, we can find seasonal and perennial weeds.

Damanganga river in its upper reach has Teak mixed forest and agricultural areas. Areas in upper reach downstream of the dam have casuarinas plantation with rooted macrophytes like lotuses in the immediate riverine region. In the middle reach of the river, we have casuarinas plantation and different species of grasses in the immediate riverine region. In lower reach, we have rice cultivation land, mixed plantation of mango, sapodilla, teak and casuarina, mangroves and mangrove associates. Water hyacinths are present in the middle and lower reach.

Physiochemical Parameters

It is difficult to determine water quality intuitively. Most common criteria for determining the health of a water body are physiochemical parameters, hydro morphological characteristic, land use pattern and riparian vegetation study (Ofenböck, T et al., 2010). The twenty-one physiochemical parameters that were used for our study – heavy metal concentration (Chromium, Lead, Aluminum, Zinc, Boron, Iron.), pH, Sulphide, Electrical conductivity (EC), Color, Sulphate, Dissolves oxygen (DO), Biological oxygen demand (BOD), Total hardness as $CaCO_3$,Chemical oxygen demand (COD), Total dissolved solids (TDS), Chloride, Residual chlorine, Phenol compounds, Fluoride, Total ammoniacal nitrogen, Some of the parameters like pH, Electrical conductivity, Color, Dissolves oxygen (DO) were determined in situ and others were in the laboratory by standard methods of IS3025- 1987. There will be temporal as well as spatial variation in these parameters. Parameters that determine water quality are divided into biological and physiochemical. While spatial variation can be both due to natural as well as due to anthropogenic influences, temporal variation is mainly due to seasonal variation.

Method of Sample collection

Water was sampled from three points from each river – at the lower, middle and upper reach at regular interval of 15 days from January to December 2017. Water was sampled along the Damanganga River and Kolak River. Water was sampled from a depth of 40 cm from the surface as subsurface water is more stable than surface water as far as physiochemical parameters are concerned.

Cluster Analysis

Cluster Analysis is an unsupervised pattern detection method. CA is a very efficient technique of agglomerative categorization of more number of sites. Such type of clustering will generate groups with high intragroup homogeneity (Zhang et al., 2009). However, there will be heterogeneity between the groups. Cluster Analysis was used for characterization and reduction in the number of sampling sites. We have used bottom-up or agglomerative hierarchical clustering and performed Cluster Analysis based on the Centroid method of SPSS version 20. Centroid method of clustering measures the distance between the means of the two clusters. At each step, we combine two clusters that have the least centroid distance.

Principle Component Analysis

Principal Component Analysis is a mathematical robust technique that transforms a number of possible correlated dimensional variables into a smaller number of uncorrelated dimensionless variables contains most of the information.

Before applying PCA, The KMO statistic and Bartlett's test was performed on data set to check the suitability of PCA. The KMO statistic measures the sampling adequacy, which can vary from 0 to 1. It indicates the degree to which each variable in a set is predicted by the other variables. Hair et al., (2006) suggest accepting a value of 0.5 or more. Bartlett's test of sphericity is a statistical test for the presence of correlations among variables, For PCA some relationships between variables are needed. Thus, a significant Bartlett's test of sphericity is required, say $p < .005$. This study comprises application of PCA to analyze water quality dataset obtained from Kolak and Damanganga River in Valsad district, Gujarat, India. Statistical calculations were performed using the "Statistical Package for the Social Sciences Software - SPSS 20 for Windows".

RESULTS AND DISCUSSION

Descriptive Analysis

Descriptive statistics used in this present study are the minimum, maximum, mean, median, skewness and standard deviation of parameters as shown in (Table 1). It is clear that EC, TDS, hardness, and chloride are dominant parameters with high mean, suggesting their common origin. Mean value of pH slightly higher. Here COD< BOD< DO showing anthropogenic activity. Some parameters tested such as heavy metals found in trace amount during lab analysis were excluded from the statistical analysis. Here we observe from the standard deviation that pH, color, total ammoniacal nitrogen, DO, nonheavy metals, fluoride, and residual chlorine does not show much deviation from mean which means that there is not much spatial and seasonal variation in these physiochemical parameters. On the other hand parameters such as TDS, EC, BOD, COD, total hardness, total ammoniacal nitrogen, sulfate, and chloride shows much deviation from the mean that is it shows spatial and temporal variation (Table 1).

Cluster Analysis

In this study, sampling sites classification was done by the use of hierarchical agglomerative cluster analysis by squared Euclidean distance as the similarity measure, Centroid method of linkage and dendrogram (figure 2) was generated. Spatial cluster analysis results were based on internal homogeneity or closeness and the difference in water quality at various sampling sites. Thus 3 clusters were generated from 6 sampling sites of the two rivers on the basis of water quality. Based on the results of spatial cluster analysis, results are concluded.

Cluster 1- It contains the upper and middle sites of Kolak River and upper site of Damanganga. These three homogenous sites have low pollution level of water. The relatively less polluted water site suggests the self-purification capacity of the river.

Cluster 2 – It contains Kolak River in its lower reach which has intermediate pollution load.

Cluster 3- It contains sites of Damanganga River in its middle and lower reaches, which suggests their homogeneity. These sites have high pollution load. The self-purification property of water is not enough for neutralizing of high pollution load.

KMO and Bartlett's test

Kaiser-Mayer-Olkin is a measure of sampling adequacy which measures the level of the correlations between variables to determine whether one can continue with the PCA. KMO value of our data set is 0.902 (Table 2), the value is greater than 0.5 indicates that the sum of partial correlations is not relatively greater than the sum of correlations and PCA should yield distinct and reliable factors and could be used.

Bartlett's test of sphericity indicates the presence of correlations among variables, providing the statistical probability. Bartlett's test of sphericity value is 0 (Table 2) which is less than 0.005, indicates that variables are adequately related to being suitable for PCA.

Eigenvalues

PCA extracts eigenvalues which are the list of factor loading from the covariance matrix of original variables and produces new orthogonal variables. The eigenvalues is a measure of the data variance explained by each of the components. The PCA interpreted that the Eigenvalue (Table 3) of the first two components is responsible for 77.26 % variance. Component 1 and component 2 is responsible for 67.22% and 10.04 % variance respectively.

Component plot interpretation

Varimax Rotation used to rotate the component matrix (as summarized in Table 4) to reduce the overlap of original variables over each PC and obtain orthogonal variable (varifactors) that gives better representation without any loss of information. Component one consisting of strong positive loading of total hardness, electrical conductivity, total dissolved solids, sulfate, chloride, boron, iron, and residual free chlorine. This factor group is inorganic, highly and positively contributed by the variables related to natural factors (erosion) as well as altered land use pattern. The existence of lots of ions and their compound led to high loading of these variables. Component two positive load of pH, total ammonia, BOD, COD, zinc, color and fluoride and the negative load of dissolved oxygen. This factor group is organic, highly contributed by the variables related to uncontrolled sewage and industrial discharge. The existence of high organic matter indicates low aquatic diversity.

Reduced Parameters

In rotated component plot (Fig 3), variables are clustered on the basis of closeness of their factor loadings. We have narrowed down the 6 identified cluster to six variable on the basis of importance, relevance, easy to measure and representative as DO (an indicator of pollution level and nature of living and nonliving organic matter), pH (is an indicator of nature of biomass), COD (an indicator of total oxidizable matter in water, is a better indicator of oxygen level of water), total ammoniacal nitrogen (an indicator of agricultural runoff load), EC(an indicator of external input in the form of either effluent or municipal sewage) and total hardness (is an indicator of external input as well as the nature of parent rock of soil. For better clarity and to lessen economic cost we reduce the number of variables. Further monitoring will include the study of only these six parameters.

Interpretation of pollution load through PCA

The score plot in figure 4 reveals the water quality at various sites of the river expresses in a two-component model – inorganic (Component 1 – x-axis) and organic (Component 2 – y-axis). The upper and middle site of Kolak River and upper site of Damanganga River has lower organic and inorganic loading. The middle reach of the Kolak River has intermediate organic loading and lower inorganic loading. The middle reach of the Damanganga River has the highest organic loading and intermediate inorganic loading. The lowest reach of Damanganga River has the highest inorganic loading and low organic loading. These three clusters were also observed in Dendrograms of CA. Kolak has a continuous gradient of organic and inorganic loading as it is comparatively less subjected to industrial effluents. Damanganga, on the other hand, shows abnormality due to the release of water from industries and CETP and in the lower course due to construction work of bridge and greater human interferences.

In this study, Cluster Analysis and Principal Component Analysis techniques were used to evaluate the water quality data set of Kolak and Damanganga Rivers, Valsad, Gujarat, India. Cluster Analysis was used to efficiently categorize water sampling sites based on their level of pollution. Hierarchical Clustering grouped several sites into three categories based on their pollution level. Based on this informative study we can design a sampling strategy having a reduced number of the monitoring station and associated cost.

PCA identified two pollution sources for the groups such as organic and inorganic. During our course of study, twenty-one physiochemical parameters used were reduced to six using PCA to get a simplified description of our rivers. Six parameters namely pH, DO, COD, Total ammoniacal nitrogen, Total hardness, and EC represents water quality. These factors are mainly due to industrialization, bricklaying, stone crushing, and other anthropogenic activities. For periodic monitoring of water bodies, these six representative parameters are easy and cost-effective.

The technique of data reduction both in sampling sites and physiochemical parameters could be extended to river waters, lake and ground waters quality analysis in tropical climates. This technique provides an optimal sampling strategy and crude guideline for environmental management. These techniques have already been used in many countries with much success in environmental engineering and management, should be practiced in India also.

Water quality affects the biodiversity of the aquatic ecosystem and its surrounding ecotone. By determining the water quality we can find out the stress factors faced by an aquatic ecosystem and its surrounding ecotone, thus remedial measures to preserve biodiversity. Reduction of sampling sites and parameters will simplify our study and help environmental monitoring and management to predict the future biodiversity of the area.

Table 1. Descriptive Statistic of Physiochemical parameters

Parameter	Unit	Min	Max	Mean	Median	SD	S
pH	-	6.0	8.7	7.3	7.2	0.6	-0.05
EC	µs/cm	198	11268	2063	1159	2274	1.98
Color	Hzn/Unit	1	30	10	8	7	1.04
DO	mg/l	1.9	7.5	5.4	5.8	1.4	-0.49
BOD	mg/l	1	570	55	30	82	3.82
COD	mg/l	1	1403	150	85	209	3.65
TDS	mg/l	7.5	8914	1205	683	1432	2.56
TH	mg/l	24	3627	560	359	622	2.70
Chloride	mg/l	9	3124	385	212	495	2.65
RFC	mg/l	0	3.2	0.7	0.7	0.6	0.83
Fluoride	mg/l	0	4.5	1.6	1.5	1.1	0.65
Sulphate	mg/l	10	678	120	44	152	2.11
TAN	mg/l	0	96	15	9	17	2.01
Zinc	mg/l	0	8.5	2.6	1.8	2.0	0.77
Iron	mg/l	0	8.8	0.9	0.7	1.1	3.64
Boron	mg/l	0	3.1	0.4	0.3	0.4	2.24

SD – Standard Deviation, S – Skewness, EC - Electrical conductivity DO - Dissolved Oxygen, TH - Total Hardness, RFC - Residual free Chlorine, TAN - Total Ammoniacal Nitrogen

Table 2. Kaiser – Meyer – Olkin and Bartlett's Test

Kaiser–Meyer–Olkin Measure of Sampling Adequacy		0.902
Bartlett's Test of Sphericity	Approx. Chi-Square	2984.728
	Df	120
	Sig.	0.000

Table 3. Eigenvalues

Component	Initial Eigen Values		
	Total	% of	Cumulative
1	10.76	67.22	67.22
2	1.61	10.04	77.26
3	0.86	5.37	82.63
4	0.73	4.59	87.22
5	0.41	2.54	89.76
6	0.33	2.07	91.83
7	0.31	1.91	93.74
8	0.24	1.53	95.27
9	0.21	1.29	96.56
10	0.18	1.12	97.68
11	0.13	0.82	98.50
12	0.12	0.75	99.26
13	0.08	0.49	99.75
14	0.03	0.17	99.91
15	0.01	0.07	99.99
16	0.00	0.01	100.00

Table 4. Rotated Component Matrix

Parameter	Component	
	1	2
TH	0.956	0.088
TDS	0.925	0.232
EC	0.909	0.336
Sulphate	0.849	0.308
Boron	0.817	0.337
Iron	0.808	0.251
Chloride	0.798	0.457
RFC	0.686	0.437
BOD	0.308	0.853
COD	0.337	0.852
Fluoride	0.517	0.705
DO	-0.575	-0.685
Color	0.516	0.679
Zinc	0.540	0.671
TAN	0.598	0.658
pH	-0.066	0.527

EC - Electrical conductivity DO - Dissolved Oxygen, TH - Total Hardness, RFC - Residual free Chlorine, TAN - Total Ammoniacal Nitrogen

Figure 1. Water sampling sites along the two rivers

Kolak river sampling sites -1A (Salvav village), 1B (Tukawara village), 1C (Vatar village); Damanganga river sampling sites – 2A (Chanod village), 2B (Namdha village), 2C (Zari village)

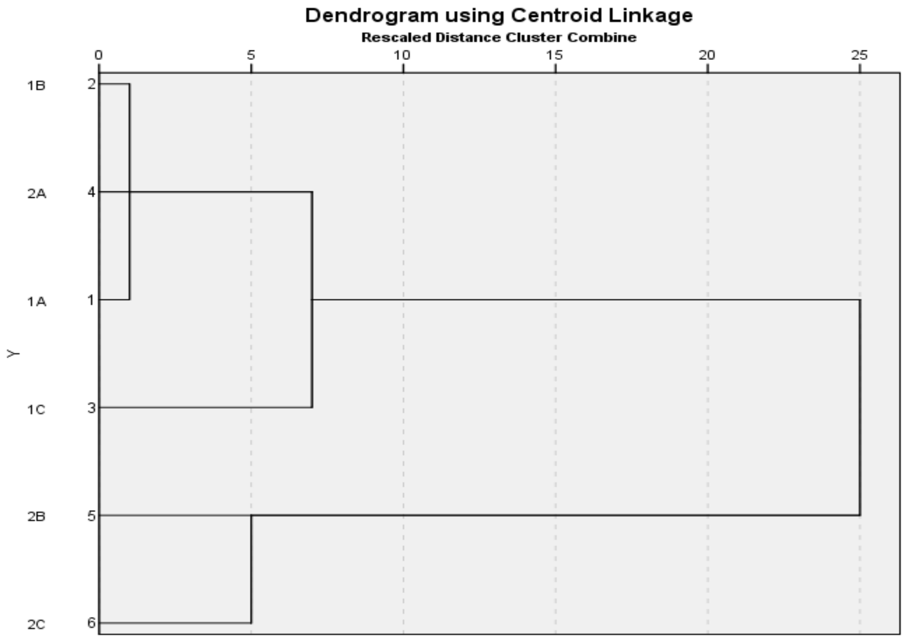

Figure 2. Dendrogram showing spatial clustering of sampling sites (Kolak River sites – 1A, 1B, 1C; Damanganga River sites – 2A, 2B, 2C)

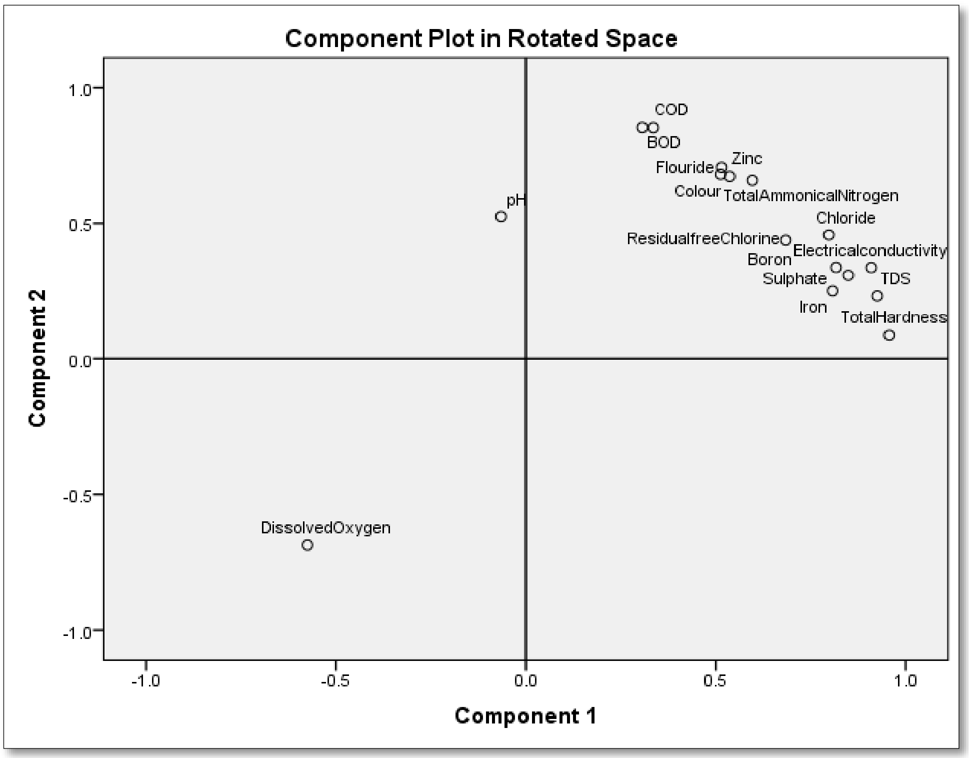

Figure 3. Cmponent plot of parameter in rotated space

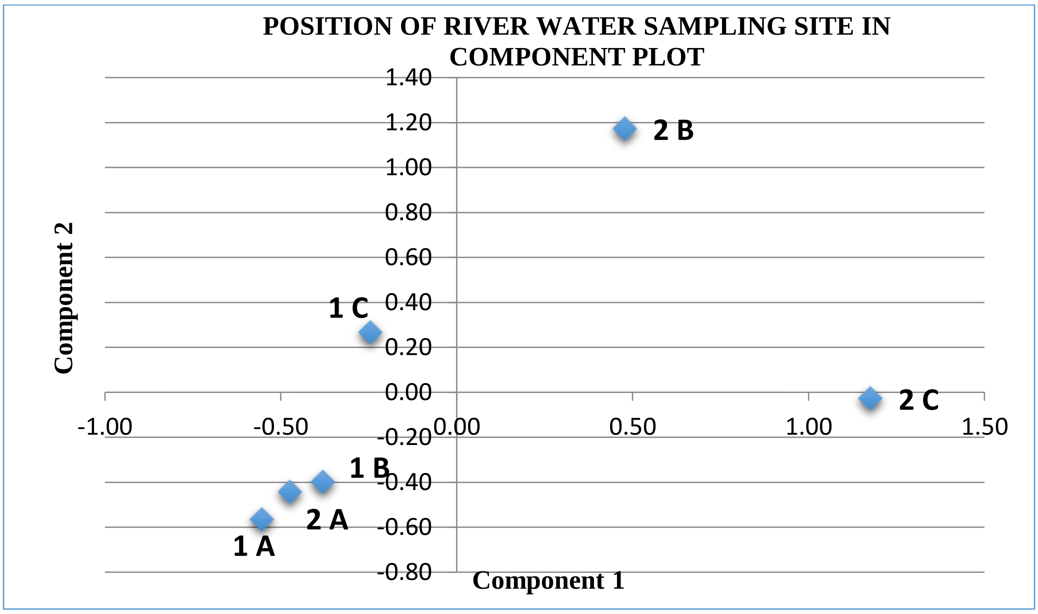

Figure 4. Score plot of sampling sites

Kolak River sampling sites – 1A (upper reach), 1 B (middle reach), 1 C (lower reach); Damanganga River sampling sites – 2 A (upper reach), 2 B (middle reach), 2 C (lower reach)

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