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Multivariate Analysis for the Water Quality Assessment in Rural and Urban Vicinity of Krishna River (India)

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Abstract: Water quality has degraded dramatically in the Krishna River (India) due to point and non-point sources. Present investigation aims to assess temporal variations of physical and chemical parameters of the river. Environmental data from rural and urban areas for the period 2007–2012 were compared. A statistical analysis was carried out with six environmental variables considering a multivariate system, analysis of variance and principal component analysis. Statistical analysis divided the river into two zones with different degrees of contamination. The most polluted zone is due to pollution inputs of municipal and industrial origin; this region showed a remarkable deterioration in water quality, mainly due to wastewater discharges.

Key words: Water quality, multivariate analysis, environmental variables, Krishna river.

Introduction

The economic development, the industrialization and the urbanization, together with the demographic advancement lead to a significant growth in water consumption and contaminating wastage in water bodies. A large number of rivers and streams are heavily contaminated due to the anthropogenic activities such as industrial and sewerage wastage (Jonnalagadda et al., 1991; Jonnalagadda and Mhere, 2001; Koukal et al., 2004; Wunderlin et al., 2001).

Rivers are among the most vulnerable water bodies facing pollution because of their role in carrying municipal and industrial wastes and run-offs from agricultural lands in their huge drainage basins. The surface water quality is very sensitive issue and it is of great environmental concern worldwide. Urban and industrial effluents are considered as being major sources of chemicals and nutrients to aquatic ecosystem. The concentration of toxic chemicals and biologically available nutrients in excess can lead to diverse problems such as toxic algal blooms, loss of oxygen, fish kill, loss of biodiversity and loss of aquatic plant beds and coral reefs (Voutsa et al., 2001).

Effective monitoring of physicochemical and microbiological parameters is required for prevention of river pollution (Bonde, 1977; Ramteke et al., 1994). Long-term surveys and monitoring programmes of water quality are satisfactory approaches to improve the knowledge of river hydrochemistry and pollution, but they produce large sets of data which are often complicated to interpret (Massart and Kaufman, 1983). The problem of data reduction and interpretation of multi-constituents chemical and physical measurements can be approached through the application of multivariate statistical analysis (Wenning and Erickson, 1994). In recent years many studies have been done using principal component analysis in the interpretation of water quality parameters (Lohani, 1984). PCA has been successfully applied to sort out hydrogeological and hydrogeochemical processes from commonly collected groundwater quality data (Jayakumar and Siraz, 1997;

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Salman and Abu-Raka'h, 1998; Praus, 2005). A statistical model which is based on the PCA for coastal water quality data from the Cochin coast in South West India was constructed, explaining the relationship between the various physicochemical variables that have been monitored and effect of environmental condition on the coastal water quality (Iyer et al., 2003). PCA technique has been used to estimate spatial and temporal patterns of heavy metal contamination (Shine et al., 1995), and investigate nutrient gradients within an eutrophic reservoir (Perkins and Underwood, 2000). Many researchers have used these techniques for groundwater quality (Gangopadhyay et al., 2001; Winter et al., 2000).

The Krishna river is the second largest eastward draining, perennial river in the Peninsular India. Krishna basin extends over an area of 258,948 km^2 which is nearly 8% of total geographical area of the country. Krishna river rises in the Western Ghats at an elevation of about 1337 m, just north of Mahabaleshwar, about 64 km from the Arabian Sea and flows for about 1400 km and outfalls into the Bay of Bengal. The principal tributaries joining Krishna are the Ghataprabha, Malprabha, Bhima, Tungabhadra, Musi and Koyana. The important soil types found in the basin are black soils, red soils, mixed soils, red and black soils, and saline soil. Predominant soil types in the area are sandy loams and loams. There are several environmental studies of the Krishna river basin, from the biological and geological points of view (Prasad and Patil, 2008; Jayalakshmi et al., 2011; Mohan et al., 2011), but the present investigation aimed to evaluate the water quality of river Krishna using multivariate analysis for interpretation of water quality.

Ecologically, this is one of the disastrous rivers in the world, in that it causes heavy soil erosion during the monsoon season. The average annual rainfall in the river basin is about 780 mm. The wet season sets in by the middle of June and withdraws by the middle of October. About 90% of the rainfall occurs during the wet season (June-October) and during the rest of the year (dry season) there is very little rainfall with no regular pattern. The important land uses include agricultural land (double crop – 35 %; single crop – 25 %), forests (15%), waste land (15%) and mixed land use (10%).

The present investigation was carried out in Karad (urban) and Rajapur (rural) areas situated on the banks of river Krishna in the state of Maharashtra. The purpose of this study is to assess the dynamics of water quality, through the analysis of physical and chemical parameters in the longitudinal segment selected; the evaluation of seasonal differences and the determination of riparian water quality.

Materials and Methods

The data was collected from Central Pollution Control Board of India for the period 2007 to 2011. It was arranged according to matrix array with six row samples and six column variables for both Karad and Rajapur. Environmental data was standardized in order to obtain comparable (dimensionless) scales (Clarke and Warwick, 1994). The water quality parameters were analyzed statistically by using SPSS-16 software package. In order to evaluate the water quality parameters descriptive statistics were calculated. Correlation between the water quality parameters were studied by using Karl-Pearson's Correlation Coefficient. Principal Component Analysis was used for dimensionality reduction in a data set by retaining those characteristics of the data set that contribute most to its variance, by keeping lower order principal components and ignoring higher order ones. PCA is very useful in the analysis of data corresponding to large number of variables. It has been widely used, as they are unbiased methods which can indicate associations between samples and variables (Wenning and Erickson, 1994). It was used to reduce the dimensionality of the data set by explaining the correlation among a large set of variables in terms of a small number of underlying factors or principal components without losing much information. Independent sample *t*-test was used to compare means for two groups.

Results and Discussion

The annual change in the physico-chemical and bacteriological parameters and descriptive statistics of Karad and Rajapur are represented in Tables 1, 2 and 3. The coefficient of variation showed that parameters like BOD, COD, nitrate and fecal coliform vary significantly along the sites and time period. Average values of pH were slightly acidic at both sites; these values were within acceptable ranges to support aquatic life. pH values below 6.5 and above 9, sustained for a long period, could affect fish development and reproduction (Boyd, 1982; FISRWG, 1998). Biochemical oxygen demand showed a significant variation between the rural and urban areas. Due to the heavy contamination of sewage from urbanized area, the population of fecal coliform increases leading to the high biochemical oxygen demand.

Table 1: Annual change in the physico-chemical and bacteriological parameters in Krishna river at Karad

	pH	*DO*	*BOD*	*COD*	*Nitrate*	*Fecal coliform*
2007	8.0025	6.4375	7.45	0	0.179	53
2008	8.02375	6.1725	8.1	20	0.113875	160
2009	7.871667	5.989167	6.75	24	0.400583	185.8333
2010	7.9125	5.81	5.658333	20	0.818833	165.9091
2011	7.824167	5.073333	5.816667	21.66667	0.429583	210.5833
2012	7.733	5.303	6.66	22.4	0.264	240

Table 2: Annual change in the physico-chemical and bacteriological parameters in Krishna river at Rajapur

	pH	*DO*	*BOD*	*COD*	*Nitrate*	*Fecal coliform*
2007	7.266667	6.5	2.266667	0	1.793867	5
2008	7.015	6.01	2.62	0	1.34127	7.6
2009	7.305833	6.083333	2.516667	24	1.7525	7
2010	7.775	6.144444	2.56	40	1.15972	4.1
2011	6.968182	5.209091	3.618182	27.55556	1.085	5.181818
2012	7.474286	6.5375	2.8	20	1.493333	7

Table 3: Descriptive statistics of environmental variables at two study sites (2007-2012)

Variables		*Karad (Urban area)*	*Rajapur (Rural area)*
pH	Mean	7.8946	7.3008
	SD	0.1098	0.2995
	CV	1.3904	4.1021
Dissolved Oxygen	Mean	5.7976	6.0807
	SD	0.5208	0.4803
	CV	8.9827	7.8981
B.O.D.	Mean	6.7392	2.7303
	SD	0.9362	0.4680
	CV	13.8925	17.1400
C.O.D.	Mean	21.6133	27.8889
	SD	8.9533	15.8821
	CV	41.4247	56.9477
Nitrate	Mean	0.3676	1.4376
	SD	0.2527	0.2967
	CV	68.7275	20.6351
Fecal Coliform	Mean	169.2210	5.9803
	SD	64.1869	1.4026
	CV	37.9308	23.4544

**Source:* Central Pollution Control Board, India.

The riparian ecosystem is undergoing a critical condition; therefore, restoring measures are required to be implemented immediately. Unfortunately, the same scenery can be found in other rivers around the world (FISRWG, 1998; Cairns, 2006).

Correlation of Physico-chemical Variables at Karad

Highly positive correlation was observed between dissolved oxygen and pH and also FC and COD (Table 4). Decrease in pH of the river waters was due to decomposition of the inundated terrestrial vegetation of the littoral zone following increased water levels. Decomposition reduced the amount of dissolved oxygen, while increasing the amount of carbon dioxide in the affected environment which accounted for the positive correlation between pH and DO (Araoye, 2009). Similar observation was reported in Asejire Lake Nigeria (Egborge, 1977) and also in Jebba Lake, Nigeria (Adeniji, 1991). Highly negative correlation was observed between FC and DO as well as nitrate and BOD. Increase in number of fecal coliform reduced the dissolved oxygen causing increase in BOD. Increase in BOD suggests the increase of aquatic microbes which consume most of the nitrate available, reducing the nitrate values of the water. Dissolved oxygen had a negative correlation with temperature, because the

Table 4: Correlation matrix of physico-chemical variables in Karad

	Correlations					
	pH	*DO*	*BOD*	*COD*	*Nitrate*	*CF*
pH	1.0000					
DO	0.8544*	1.0000				
BOD	0.6045	0.6813	1.0000			
COD	-0.5607	-0.6188	-0.3794	1.0000		
Nitrate	-0.2410	-0.3002	-0.8587*	0.3323	1.0000	
CF	-0.8097	-0.8355*	-0.4498	0.9152*	0.2287	1.0000

*Correlation is significant at the 0.05 level (2-tailed).

solubility of this gas decreases with increasing water temperature and increasing organic loading. Phosphorus correlated negatively with dissolved oxygen, since the nutrient augment permits algal growth. Similar conclusions were obtained by Vega et al. (1998).

Principal component analysis of Karad resulted in the biplot (Figure 1). Table 5 represents the determined initial principal components (PC-I), its eigen values and percent of variance contributed in each principal component. Rotated component matrix of eigen values for Karad were represented in Table 6. Four components were obtained <1 eigen values. Almost 87% of the total variance in the water quality parameters was observed only in two principal components. 65.95% variability of the original data was explained by first principal component (PC-1) and 21.40% was explained by second principal component (PC-2). pH and DO with strong factor loadings are the most important parameters in water quality variations for first PC and represents the physicochemical source of the variability (Mishra, 2010). The second PC was loaded with biological oxygen demand (BOD) which indicates the entrance of waste water from the domestic and industrial drainage and its organic load disposed into the river from Karad city.

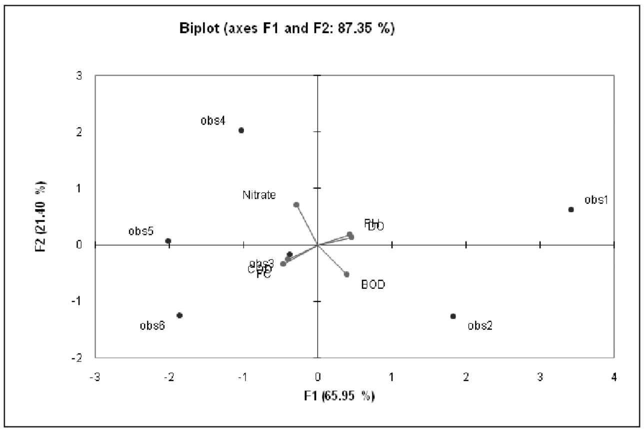

Figure 1: PCA biplot of environmental variables of Krishna river at Karad (2007-2012).

Correlation of Physico-chemical Variables at Rajapur

High negative correlation was observed between BOD with DO (Table 7). Dissolved oxygen from water is used by fish and insects that live in these waters. Dramatic increase in the number of organisms in a waterbody can lower the dissolved oxygen causing increase in BOD.

Table 5: Principal component analysis of physico-chemical variables in Karad

Comp.	*Initial Eigen values*			*Extraction sums of squared loadings*			*Rotation sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	3.9571	65.9521	65.9521	3.9571	65.9521	65.9521	3.2972	54.9530	54.9530
2	1.2842	21.4025	87.3546	1.2842	21.4025	87.3546	1.9441	32.4016	87.3546
3	0.5971	9.9520	97.3066						
4	0.1449	2.4151	99.7217						
5	0.0167	0.2783	100.0000						
6	-3.8E-16	-6.3E-15	100.0000						

Table 6: Rotated component matrix of Eigen values for Karad

	Component	
	1	2
pH	.857	.250
DO	.865	.321
BOD	.389	.903
COD	-.835	-.147
Nitrate	-.083	-.964
Fecal coliform	-.979	-.109

Extraction Method: Principal Component Analysis.
Rotation Method: Varimax with Kaiser Normalization.

Principal component analysis of the Rajapur resulted in the biplot (Figure 2). Table 8 represents the determined initial principal components (PC-I) and its eigen values and percent of variance contributed in each principal component. Rotated component matrix of eigen values for Karad were represented in Table 9. Eigen values of four components were <1, 82% of the total variance in the water quality parameters was observed only in two principal components. 48% variability of the original data was explained by first principal component (PC-1) and 34% was explained by second principal component (PC-2). Nitrate and DO with strong positive loading value are the most significant parameters contributed to water quality variation in first PC of Rajapur and represents influence of non-point sources such as agricultural runoff. The second PC was loaded with chemical oxygen demand (COD) and pH with positive value.

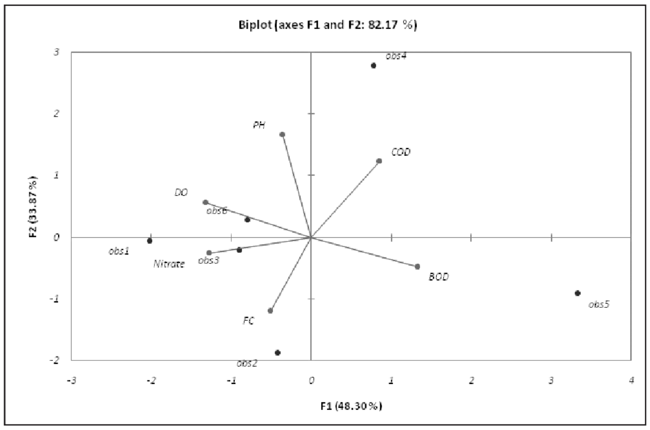

Figure 2: PCA biplot of environmental variables of Krishna river at Rajapur (2007-2012).

Differences in Water Quality of Karad and Rajapur

The Independent-Samples *t*-Test procedure compares means for two groups of cases. Present investigation attempted to compare the means of different water quality parameters of the two sites Karad (urban) and Rajapur (rural).

Analysis showed that the null hypothesis is rejected for four parameters viz. pH, BOD, nitrate and FC at 1% level of significance (Table 10). pH which is a representative of the hydrogen ion concentration showed a significant difference between the urban and rural areas which may be due to the addition of mineral nutrient ions in the form of pollutants from point sources of urbanized area. Physico-chemical variables at Karad exhibited a significant decrease in water quality due to the developed anthropogenic activities in this region; similar results were found in Chocancharava river, Argentina (Gatica et al., 2012).

BOD is a measure of total microbes present in the water which consumes oxygen at a given period of time

Table 7: Correlation matrix of physico-chemical variables in Rajapur

	Correlations					
	pH	*DO*	*BOD*	*COD*	*Nitrate*	*CF*
pH	1.0000					
DO	0.5635	1.0000				
B.O.D	-0.4534	-0.8366*	1.0000			
C.O.D.	0.5630	-0.3218	0.3747	1.0000		
Nitrate	0.0273	0.66273	-0.697	-0.5162	1.0000	
CF	-0.4159	0.1541	-0.079	-0.47	0.3253	1.0000

*Correlation is significant at the 0.05 level (2-tailed).

Table 8: Principal component analysis of physico-chemical variables in Rajapur

Comp.	*Initial Eigen values*			*Extraction sums of squared loadings*			*Rotation sums of squared loadings*		
	Total	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*	*Total*	*% of variance*	*Cumulative %*
1	2.8983	48.3049	48.3049	2.8983	48.3049	48.3049	2.8104	46.8393	46.8393
2	2.0320	33.8661	82.1710	2.0320	33.8661	82.1710	2.1199	35.3317	82.1710
3	0.5960	9.9339	92.1049						
4	0.3228	5.3804	97.4853						
5	0.1509	2.5147	100.0000						
6	0.0000	0.0000	100.0000						

and indicates the level of organic pollution occurred at the site; significant difference between two stations was observed for BOD and fecal coliform due to the addition of heavy sewage from the municipal vicinity. Nitrate concentration showed significant difference between two stations due to the effect of agricultural run-off from the cultivated lands of Rajapur where the usage of chemical fertilizers (NPK) is communal.

Table 9: Rotated component matrix of Eigen values for Rajapur

	Component	
	1	2
pH	.535	.816
DO	.956	.018
BOD	-.943	.031
COD	-.327	.846
Nitrate	.775	-.416
Fecal coliform	.115	-.751

Extraction method: Principal component analysis.
Rotation method: Varimax with Kaiser normalization

Table 10: Independent sample *t*-test for comparison of means of the environmental variable at two sites

	t value	*p value*
pH	4.560	0.001
DO	-0.979	0.351
BOD	9.382	0.000
COD	-0.490	0.635
Nitrate	-6.726	0.000
CF	6.228	0.000

*$p \leq 0.05$ represents statistically significant differences between variables.

Since the riparian forests are vanishing, their original function, as nutrient sieve and lethal element cleaner, is being affected (Sweeney et al., 2004). The features of riparian woods have changed completely, from the three-layer condition of the original forest to isolated plantations of exotic trees and to the status of small grasslands. The loss of vegetal covering causes an increase in river bank erosion and the drag of pollutants and solid materials from agricultural runoffs carrying nitrates and phosphates (Shafroth et al., 2002; Paul and Meyer, 2001). When this scenery is sustained over time, the disturbance and pollution risk increases causing severe damage to the natural health of the riparian environment.

Conclusion

The results of the multivariate techniques used in this study seem to give evidence to the differentiation of the urban waters from rural waters obtained from the environmental approach. The correlation coefficient gives an idea about the relation between environmental parameters, helping in decision making to conservation strategies. Principal component analysis resulted in knowing the important parameters like nitrates and dissolved oxygen affecting the water quality in Rajapur and the similar role was played by pH and dissolved oxygen at Karad. Hence controlling these environmental parameters can help to save the pristine nature of the water.

Karad is associated with urbanization, sewage, industrial discharge and agricultural runoff, in contrast to Rajapur where anthropogenic activity is restricted to agricultural uproar. The independent sample *t*-test showed statistically significant differences in most of the variables between two stations. Sampling sites located after sewage discharge showed the most significant pollution levels. Consequently, eutrophication problems are caused by increased concentration of primary nutrients.

Riverine ecosystems primarily have two functions; fundamental and contradictory, at the same time. The socio-cultural role covers public spaces, landscaping, recreational purposes and the ecological role in maintaining processes such as conservation of biodiversity and water quality. Thus, government agencies should take political control about these ecosystems.

The information provided by this study demonstrates the urgency for an immediate course of action towards ecological restoration. Control agencies should be able to maintain balance between both roles, allowing riparian use and expansion of anthropogenic activities, without causing deterioration and ecological disturbance.

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