

Assessment of nutrients using multivariate statistical techniques in estuarine systems and its management implications: a case study from Cochin Estuary, India

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Abstract

The status of nutrients in Cochin Estuary in relation with other physico-chemical variables was assessed using monthly data from seven locations for a period of 3 years. Seasonal comparative assessments were made and the probable sources of nutrients were modelled using principal component analysis (PCA). The results pointed out that the nutrients have higher concentration in premonsoon season compared with other seasons. The correlation coefficients of nutrients pointed out that strong correlation exists indicating that their source of origin could be same. Factor analysis extracted three principal components (PCs) in which the first component attributed to run-off, the second to influx of marine water and the third to intensive human activities. The proposed statistical model based on PCA gave a reasonable explanation on relation between physico-chemical parameters and environmental factors which have far reaching implications in the management of water systems.

Introduction

Nutrient enrichment of rivers, lakes, groundwaters and tidal waters is considered to be one of the major environmental problems in many countries (Heathwaite *et al.* 1996; Smith *et al.* 1999; Oczkowski & Nixon 2008). Although it can stimulate the growth of plants (algae as well as higher plants), nutrient enrichment ultimately leads to the degradation of entire ecosystems if not controlled in a satisfactory manner. In recent decades, population growth and related activities, such as various agricultural practices and sewage run-off from urban areas, have increased nutrient inputs by many times to the levels that occur naturally. The United Nations Environment Program (UNEP) has reported that 150 coastal areas worldwide are now starved of oxygen as a result of the decomposition of algal blooms fuelled by nutrients from agricultural run-off of fertilizers and sewage from large cities (UNEP 2003). Therefore, the quantitative and qualitative assessment of nutrient inputs to ecological systems is considered as essential to develop a robust and transparent nutrient management strategy, particularly in terms of targeting nutrient control options.

Multivariate statistical techniques are powerful tools for analysing large numbers of samples collected in surveys, classifying assemblages and assessing human impacts on ecosystem conditions (Gauch 1982; Digby & Kempton 1987; Reynoldson *et al.* 2001; Cao *et al.* 2002). Alley (1993) presented an overview of multivariate statistical techniques that have been applied to examine phenomena associated with water quality. Factor analysis is a multivariate statistical techniques used to understand the correlation structure of water quality data and identify the most important factors contributing to the data structure (Padro *et al.* 1993; Barbieri *et al.* 1999; Iyer *et al.* 2003). Several studies have used factor analysis to identify primary sources of contamination (Reisenhofer *et al.* 1995; Borovec 1996; Vega *et al.* 1998; Singh *et al.* 2005) and to find associations between parameters so that the number of measured parameters can be reduced (Parinet *et al.* 2004; Zeng & Rasmussen 2005).

Cochin Estuary (9°54'–10°00'N and 76°12'–76°19'E) is one of the largest estuarine systems located in the south-western India. It drains six major rivers in the Province of Kerala into the Arabian Sea through a narrow mouth of 50 m width. During the last 50 years, the effluent discharge from Cochin Industrial City has increased from a

negligible level to 6.5 million m³/day (Gopalan 2002). The indiscriminate use of fertilizers, insecticides, fungicides and municipal waste causes considerable damages to the water quality of riverine, estuarine and marine systems (Ouseph *et al.* 2004a–c). The bordering areas and islands in the estuary are centres of intense human activity caused by the establishment of the Cochin Port in 1950s. Fishing is one of the major incomes for the local community. In addition, the area is listed as one of the top 50 destinations in the global tourism map, increasing the pressure on the ecosystems.

The ecological studies in the Cochin Estuary were pioneered by Sankaranarayanan & Qasim (1969) and Sankaranarayanan & Panampunnayil (1979). Studies carried out in the last few decades have pointed out unfavourable changes in the hydrodynamics (Madhupratap *et al.* 1977; Joseph & Kurup 1990; Balachandran 2001) and hydrobiological (Qasim 1980; Lakshmanan *et al.* 1982; Menon *et al.* 2000) conditions of the Cochin Estuary. The concentrations of dissolved, particulate and sedimentary metals are well documented (Ouseph 1992; Ouseph *et al.* 2004c; Balachandran *et al.* 2005; Joseph *et al.* 2008). Analysis of the literature showed that the sources of nutrients and its association with other physico-chemical variables were poorly studied in this highly threatened ecosystem (Joseph *et al.* 2008). The current paper analyses the status of nutrients in the estuary in relation with other physico-chemical parameters. It also addresses the influence of possible sources (natural and anthropogenic) on water quality parameters, the source apportioning of nutrients in the overall water quality variability and the probable causes of nutrient enrichment in the estuarine system.

Materials and methods

Data acquisition

Seven locations in the Cochin Estuary (Fig. 1) were measured for temperature, pH, salinity, dissolved oxygen (DO), inorganic phosphate, total phosphate, nitrite, nitrate, ammonia and total nitrogen on a monthly basis from February 2001 to January 2004. Samples were collected at two levels of the water column – surface and deep water. The estuarine system is largely influenced by the influx of freshwater, which in turn, is controlled by the monsoon season facilitating the division of the observation period into three distinct periods, namely, pre-monsoon (February–May), monsoon (June–October) and postmonsoon (November–January). Surface samples were collected using a clean plastic bucket and bottom samples by a Van Dorn sampler. All the apparatus, wherever possible, were cleaned by soaking in 6 N HCl and

subsequently washed in double distilled water. The chemicals used for the present study were of high purity Excellar and GR grade quality. Water samples were stored in prerinsed polythene bottles. Temperature, pH measurements and fixing of water samples for determining DO were done in situ and other parameters were determined in the laboratory. The water samples were analysed using APHA (1995) standard methods.

Data analysis

The observations for each parameter were divided into premonsoon, monsoon and postmonsoon seasons, and data were evaluated using central tendency (mean) and dispersion (standard deviation). To examine the suitability of the data for factor analysis, Kaiser–Meyer–Olkin (KMO) and Barlett's tests were performed. A correlation matrix was generated for understanding the degree of mutually shared variability between individual pairs of water quality parameters. The next step was the estimation of the Eigen values and factor loadings for the correlation matrix. Because lower Eigen values may contribute little to the explanatory capability of the data, only the first few factors were taken into account. The Eigen values > 1 were considered as prominent factors as per the Kaiser criterion (Kaiser 1960). After the correlation and Eigen values were obtained, factor loadings were used to measure both the correlations and regression weights between factors and variables.

Results and discussion

Physico-chemical parameters

A total of 504 observations were made for each parameter (5040 readings). The statistical summary (mean, minimum, maximum and standard deviation) of the data is shown in Table 1. Season-wise variations in water quality parameters is tabulated in Table 2. The temperature fluctuated from 22 to 34 °C (mean of 28.16 ± 1.8 °C) during the study period. In all the seasons, the temperature of the bottom water was lower than the surface water. The mean pH of the Cochin Estuary during the study period was 7.45 ± 0.43 . In the premonsoon season, the surface water observed a mean pH of 7.41 ± 0.33 , which was lowered to 7.08 ± 0.35 in the monsoon season. It increased to 7.69 ± 0.30 in the postmonsoon season. The bottom water also showed the similar tendency. This may be due to the input of freshwater in the monsoon season. Salinity showed wide variation from 0.10 to 35 with a mean value of 17.55 ± 10.64 . The surface and bottom water recorded the clear influence of freshwater during monsoon months. Higher salinity in bottom water

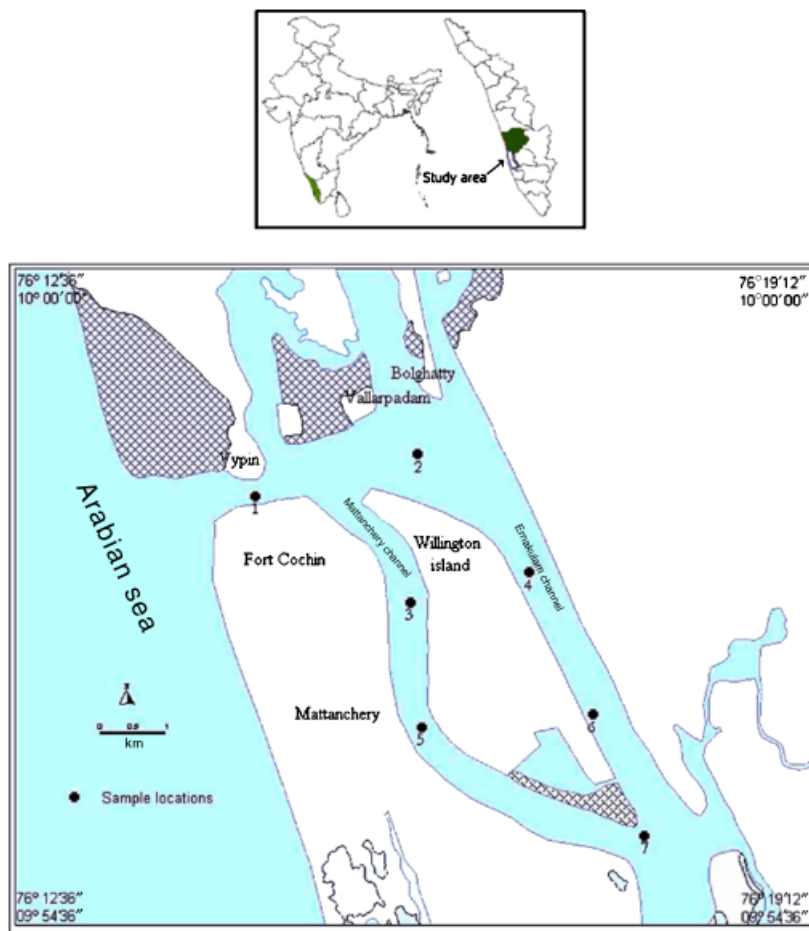


Fig. 1. Map of Cochin Estuary, Kerala State, India. The seven sampling points are marked.

Table 1 Basic statistics (mean, minimum, maximum and standard deviation) of variables in Cochin Estuary

Parameter	Unit	Minimum	Maximum	Mean	Standard deviation
Temperature	°C	22.00	34.00	28.17	1.84
pH	–	6.11	8.28	7.46	0.43
Salinity	–	0.10	35.00	17.56	10.64
DO	mg/L	2.37	7.40	5.06	0.78
Inorganic phosphate	μmol/L	0.38	12.68	3.30	2.04
Nitrite	μmol/L	0.98	51.50	9.36	7.39
Nitrate	μmol/L	0.00	21.08	2.06	3.31
Ammonia	μmol/L	0.00	2.86	0.34	0.30
Total phosphorus	μmol/L	0.70	34.21	6.49	3.50
Total nitrogen	μmol/L	5.82	93.80	25.56	14.59

DO, dissolved oxygen.

compared with surface water was due to seawater intrusion. The average DO concentration was 5.06 ± 0.78 mg/L. The surface DO values were more than that of bottom waters and overall increase in monsoon months was probably due to the influence of rain and atmospheric turbulence. The lower oxygen content at the bottom

could be attributed to oxygen consumption during decomposition of organic matter in the deeper strata of the water body (Sankaranarayanan & Qasim 1969).

Nutrient status

Generally, bottom water showed higher concentrations of nutrients than the surface water. Sankaranarayanan & Panampunnayil (1979) reported higher concentrations of nitrogen and phosphorus in the sediments in the Cochin Estuary, influenced by unabated domestic waste disposal. The higher concentration of nutrients in bottom water was probably due to the release of nutrients from the interstitial sediments owing to prevalent dredging activities. The average concentration of inorganic phosphate in the study area during the study period was 3.30 ± 2.04 μmol/L. The nitrate concentration varied from 0.98 to 51.50 μmol/L with a mean value of 9.37 ± 7.25 μmol/L. Nitrite also showed wide fluctuations depending on the season. The mean concentration of ammonia was 0.34 ± 0.30 μmol/L. The presence of ammonia indicates sewage input in surface water. Ammonia content may

Table 2 Mean value of parameters in surface and bottom waters along with their standard deviations in different seasons

Parameter	Premonsoon		Monsoon		Postmonsoon	
	Surface	Bottom	Surface	Bottom	Surface	Bottom
Temperature (°C)	29.85 ± 1.44	29.29 ± 1.39	28.25 ± 1.60	26.86 ± 1.67	27.72 ± 1.58	27.53 ± 1.34
pH	7.42 ± 0.33	7.59 ± 0.33	7.09 ± 0.36	7.35 ± 0.45	7.70 ± 0.30	7.86 ± 0.26
Salinity (p.p.t.)	29.07 ± 1.97	28.29 ± 2.15	4.57 ± 4.06	15.00 ± 9.78	22.51 ± 9.29	26.95 ± 7.78
Dissolved oxygen (mg/L)	4.97 ± 0.60	4.63 ± 0.55	5.58 ± 0.74	5.02 ± 0.87	5.24 ± 0.63	4.88 ± 0.59
Inorganic phosphate (µmol/L)	4.02 ± 1.96	5.55 ± 2.76	2.80 ± 1.16	3.06 ± 1.36	1.86 ± 0.84	2.07 ± 0.86
Nitrate (µmol/L)	10.88 ± 9.44	14.34 ± 11.64	8.21 ± 4.72	9.78 ± 4.34	4.98 ± 1.43	6.07 ± 1.93
Nitrite (µmol/L)	4.07 ± 4.77	4.48 ± 4.67	1.24 ± 2.01	1.12 ± 0.93	0.52 ± 0.27	0.59 ± 0.29
Ammonia (µmol/L)	0.30 ± 0.24	0.29 ± 0.22	0.44 ± 0.43	0.32 ± 0.36	0.36 ± 0.16	0.32 ± 0.15
Total phosphorous (µmol/L)	6.96 ± 3.12	9.54 ± 5.27	5.14 ± 1.83	6.87 ± 2.71	4.37 ± 1.81	5.53 ± 2.44
Total nitrogen (µmol/L)	28.16 ± 18.18	35.36 ± 21.28	22.68 ± 10.63	27.20 ± 10.42	16.87 ± 4.03	19.77 ± 4.81

Table 3 Correlation matrix of variables (504 observations)

Parameters	Temperature	pH	Salinity	DO	Inorganic phosphate	Nitrate	Nitrite	Ammonia	Total phosphorous	Total nitrogen
Temperature	1.00	0.08	0.09	0.00	0.29	0.05	0.18	0.18	0.29	0.05
pH	0.08	1.00	0.77	-0.00	-0.02	-0.26	-0.08	-0.08	-0.00	-0.31
Salinity	0.09	0.77	1.00	-0.21	0.01	-0.22	-0.05	-0.05	0.03	-0.24
DO	0.00	-0.00	-0.21	1.00	-0.27	-0.20	-0.17	-0.17	-0.28	-0.22
Inorganic Phosphate	0.29	-0.02	0.01	-0.27	1.00	0.41	0.42	0.42	0.69	0.45
Nitrate	0.05	-0.26	-0.22	-0.20	0.41	1.00	0.65	0.65	0.47	0.84
Nitrite	0.18	-0.08	-0.05	-0.17	0.42	0.65	1.00	0.04	0.46	0.63
Ammonia	-0.10	-0.11	-0.17	0.06	0.00	0.07	0.04	1.00	-0.06	0.05
Total phosphorous	0.29	-0.00	0.04	-0.28	0.69	0.47	0.46	0.46	1.00	0.50
Total nitrogen	0.05	-0.31	-0.24	-0.22	0.45	0.84	0.63	0.63	0.50	1.00

DO, dissolved oxygen.

also be supplemented by the Periyar River and its associated tributaries including Chitrapuzha, which flow through the industrial zones. The minimum concentration of total phosphorous was 0.70 µmol/L and the maximum was 34.21 with a mean value of 6.49 ± 3.5 µmol/L. The mean concentration of total nitrogen varied from 5.82 to 93.80 µmol/L in different seasons.

Correlation analysis

The correlation matrix of nutrients (Table 3) revealed the existence of a strong correlation between them giving an indication that their source of origin may be the same. The premonsoon season showed the highest concentration of nutrients compared with the other seasons. In the premonsoon season, the freshwater input was very low and the water input was only from the inward draining of seawater. The negative correlation between salinity and nutrients pointed out that the seawater was not the source for nutrients. Hence, it could be concluded that the sewage from Cochin City may be the possible source of nutrient enrichment in premonsoon season in the lake. Next to premonsoon season, the monsoon season was observed with reduced concentrations of nutrients. This

could possibly be due to the freshwater input from the Periyar River, which flows through the industrial and agricultural belt of Kerala and other land drainage in the immediate vicinity of the lake. Sankaranarayanan & Qasim (1969) observed freshwater run-off and land drainage as the major sources of nutrients in the Cochin Estuary in the monsoon season, which is in concordance with our study.

Factor analysis

KMO test for checking the suitability of the data for factor analysis indicated that factor analysis is useful for explaining the variance of the data (KMO measure of sampling adequacy=0.725). Also, Barlett's test of sphericity on the correlation matrix has indicated significant relationships exist among the variables (approximately $\chi^2 - 2167.374$, d.f. - 45 $P < 0.005$). Subsequent running of principal component analysis (PCA) extracted three principal components (PCs) from the variance present in the data (Table 4). The first three factors (Eigen value > 1) accounted for 65% of the observed variation in water quality observations. Additional factors provided marginally less explanatory capability and were not examined further. Factor

Table 4 Factor analysis based on principal component analysis in Cochin Estuary

Components	Eigen values		
	Total	% of variance	Cumulative (%)
1*	3.45	34.51	34.51
2*	2.00	20.03	54.54
3*	1.08	10.76	65.30
4	0.96	9.60	74.90
5	0.86	8.59	83.50
6	0.63	6.26	89.76
7	0.38	3.75	93.50
8	0.30	3.00	96.51
9	0.20	1.97	98.48
10	0.15	1.52	100.00

*Principal components extracted.

Table 5 Factor loadings of principal components (PCs) in Cochin Estuary

Parameters	PCs		
	PC ₁	PC ₂	PC ₃
Temperature	0.24	0.36	0.76
pH	-0.30	0.81	-0.17
Salinity	-0.22	0.87	-0.26
DO	-0.34	-0.32	0.46
Inorganic phosphate	0.71	0.31	0.20
Nitrate	0.85	-0.15	-0.20
Nitrite	0.77	*	*
Ammonia	*	-0.33	-0.24
Total phosphorous	0.75	0.33	0.16
Total Nitrogen	0.87	-0.17	-0.17

*Values <0.1 has not considered.

loadings (correlations between the variables and the extracted factors) for the three retained Eigen values are given in Table 5. Factor loadings <0.1 were not considered in the study. The first factor, principal component (PC₁), captured 34.5% of variance, the second principal component (PC₂) captured 20% of the variance and the third principal component (PC₃) captured 10.76% of the variance. The first PC had high loading values for total nitrogen (0.869), nitrate (0.849), nitrite (0.767), total phosphate (0.751) and inorganic phosphate (0.713). The second PC had high loadings values for salinity (0.866) and pH (0.811) while the third PC had high loadings for temperature (0.756) and DO (0.462). The first component implied the overloading of nutrients in the estuary possibly attributed to the release of nutrients from municipal waste from the surrounding Cochin City and also through the Periyar River. Sankaranarayanan & Panampunnayil (1979) attributed unabated domestic waste disposal to the degraded water quality in the estuary. Balachandran *et al.* (2005) also pointed out that freshwater run-off from Periyar River is one of the sources of nutrients in the Cochin Estuary. The second component with higher

loading values for salinity and pH clearly indicated the influx of marine water into the estuary in high tide time especially in the premonsoon and postmonsoon seasons. During this time, the values of salinity and pH have shown a steady increase compared with the monsoon season. The third component with higher loading values on temperature and DO could be linked with the intensive human activity in the area. The Cochin Port, established in the 1950s, is one of the major business and defence ports in India. In addition to tourists and fishing boats, the islands scattered in the estuary with high population density heavily depend on boat services for transportation. All these factors may have influenced temperature and DO of the estuarine system.

Conclusion and management implications

(1) The development of a nutrient management strategy is an essential component in the management of water resources because its enrichment adversely affects the normal functioning of the systems.

(2) This paper analyses the status of nutrients in relation with other physico-chemical parameters in the Cochin Estuary.

(3) The identification and apportionment of factors/sources responsible for the variability in the water quality indicated that nutrient enrichment from run-off is the major source influencing the estuarine water quality.

(4) The two run-off components are municipal waste discharge from the surrounding city, and riverine water carrying industrial and agricultural wastes.

(5) Broadly, we could classify these sources into two category; point sources (e.g. municipal and industrial waste discharge) and diffuse (nonpoint) sources which are mainly draining from fertilizer-rich agricultural fields. The improper planning of developmental activities like industrialization and urbanization had led to these point sources contributing large amounts of discharge. Intensive agriculture as a result of the Green Revolution had also contributed to the nutrient influx.

(6) The point sources are the prevalent factors in premonsoon season while the nonpoint sources are the major factors in monsoon season. Hence, there is a need to pay attention to both these aspects with respect to time in the planning stage. Controlling the wastewater flow to the estuarine system should be given priority during the premonsoon season. Basic infrastructure facilities like wastewater treatment plants should be aligned with master plans of developmental activities for achieving this objective. Optimization of fertilizer usage and construction of protective zones along river banks to prevent

leaching of nutrients from agriculture fields should also be prioritized in developmental plans of regions. In reality, these components are lacking especially in developing countries like India. So there is an urgent need to modify the present policies of development with a sustainable vision of development, to ensure the aesthetic and qualitative use of water for the future.

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