Prioritization of Water Quality Parameters for Management of a Typical Lake in South India

K.K.S. Bhatia, Omkar Singh and Suhas Khobragade
National Institute of Hydrology, Roorkee, U.A. (India)
(E-Mail: kksb@nih.ernet.in)

ABSTRACT

Water quality monitoring is expensive, and resource committed to unnecessary water quality measurements may be at the expense of a successful experimental design. Virtually, hundreds of water quality variables exist and are therefore candidates for monitoring. In view of this, a method for prioritizing their selection is important. The principal component analysis (PCA) may be used to find inter-relationship between different variables of the water quality, which helps to find out the influence of specific variables upon the patterns of water quality.

Therefore, in the present study, principal component analysis (PCA), which is a complementary approach to geochemical methods in water quality factor identification has been used in prioritizing of lake water quality parameters for the management of lake water quality. In this connection, water quality data of various physico-chemical parameters (pH, EC, DO, alkalinity, calcium, magnesium, bicarbonate, sulphate, chloride, nitrite, total phosphate, iron) pertaining to lake Oussudu was used. In the present study, six factors (total hardness, conductivity, dissolved oxygen, sulphate, nitrate and total phosphate) were found to be dominant for describing water quality pattern of the Oussudu lake, which explained a total variance of water quality data upto 87%.

The results of this study would be an important input in the form of influencing water quality parameters for management of the water quality of the Oussudu lake. The study would be useful to the local public and the concerned authorities, involved in the water resource management of Oussudu lake.

INTRODUCTION

Oussudu lake (also called Ousteri) is the largest fresh water lake in the Pondicherry region and a large number of people depend on its water, fish and other produce. It is a shallow wetland situated at 11° 57' N latitude and 79° 45' E longitude, which is close to the city of Pondicherry, India (fig. 1). Apart from the Pondicherry, the eastern and northern parts of the Oussudu lake are also lied in the Tamilnadu State. The storage capacity of the lake is 540 million cft (Selvanayaki, 1997). Apart from serving the needs of irrigation water, Oussudu lake is a major wintering spot for a large number of migratory birds and is a rich source of inland fisheries. Because of rich flora and fauna, this lake has been recognized as one of the important wetlands of Asia by the International Union for Conservation of Nature and Natural Resources (IUCN). With the demographic pressure increasing dramatically in Pondicherry during the recent years,

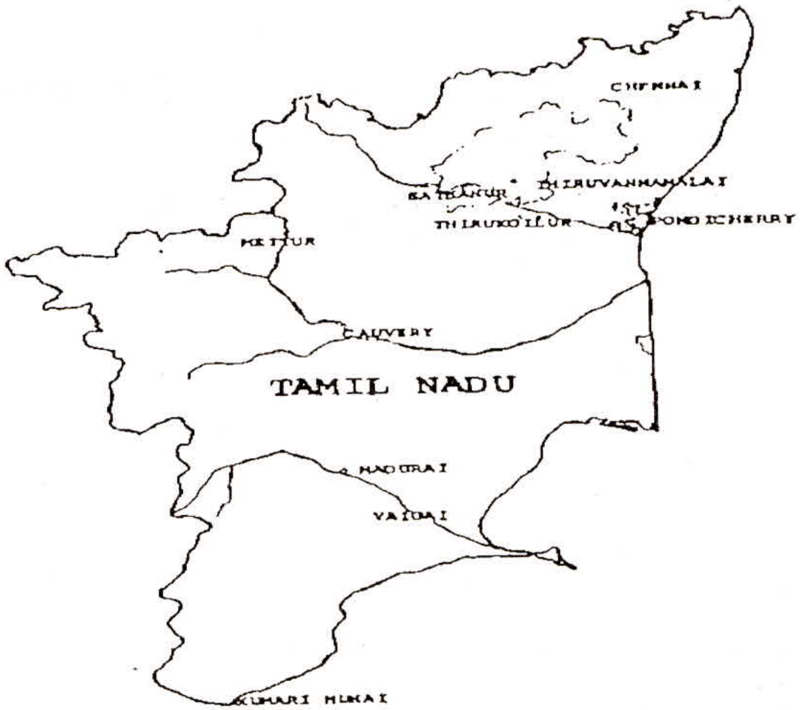

Fig. 1: Study area showing Oussudu lake

as also the demand for water, the Oussudu is now more important for the survival of the city that it was ever before.

Unfortunately, the lake did not seem to have received care and attention during last few decades. As a result, the lake catchment as well water body is facing serious threats from encroachment, poaching, and pollution. The situation reached an alarming stage during mid 1993 due to dumping of highly toxic industrial waste at the banks of the lake. In this connection, at this juncture a major non-governmental organization named COPDANET (Coastal Poor Development Action Network, Madras) launched the "save the Oussudu lake" campaign. In addition, various investigators have also reported their findings on the Oussudu in respect of limnological, biological and hydrological aspects (Chari and Abbasi, 2005; Chari et a., 2003; Selvanayaki, 1997). Therefore, keeping in view the threats of pollution in this lake, water quality studies become very essential for water resource management. Further, regular water quality monitoring being very costly has given an incentive problem to the investigators to find out an alternatives way to obtain pattern of water quality instead of regular monitoring.

Principal Component Analysis (PCA) may be used to find inter-relationship between different variables of the water quality which helps to find out the influence of specific variables upon the patterns of water quality. The main advantage of this analysis is its suitability for simultaneous analysis of large number of variables and observations. The principal component method has been used as a complementary approach to geochemical methods in water quality factor identification in the coastal plain aquifer of Israel (Melloul and Collin, 1992). In fact, this method has been used in numerous earth science branches such as hydrochemistry to assist in understanding hydrologic processes affecting ground water and soil salinity (Deverel, 1989). Vajrappa and Srinivas (1994) have also used the principal component analysis for hydrochemistry of Kabini River basin in Karnataka. Rao (2001) used principal component analysis for groundwater quality in Venkatagiri Taluq, Nellore District (A.P.).

DATA AND METHODOLOGY

In this study, water quality data of Oussudu lake was obtained from the studies conducted at the Pondicherry University, Pondicherry (Selvanayaki, 1997). The water quality parameters include: pH, electrical conductivity, dissolved oxygen, alkalinity, calcium, magnesium, bicarbonate, sulphate, chloride, nitrite, total phosphate and iron. PCA analysis was performed using Systat 10 for twelve water quality variables/parameters (v =12) pertaining to summer months having 94 spatio-temporal observations in the Oussudu lake (n =94).

The main steps of PCA include preparation of a matrix of chemical variables (v) and observations (n), finding out their eigenvalues and eigenvectors. Once a complete set of data has been collected for all the variables (v) and sampling sites/observations (n), this can be represented by a data matrix [X] of dimension v×n. The lake water quality data can be transformed prior to analysis to have normal distributions independent of measurement units by subtracting mean (v_m) from each variable (v) and dividing by standard deviation (s) of the distribution (Davis, 1986).

RESULTS AND DISCUSSION

The results of statistical analysis of Oussudu lake water quality parameters are given in Table-1. These results reveal variation (with mean values) of calcium from 4.8 to 12.8 mg/l (7.6), chloride 14 to 30 mg/l (19), electrical conductivity 200 to 290 μS/cm at 25 ^{0}C (246), alkalinity 73 to 112 mg/l (94), magnesium 8 to 25 mg/l (14), nitrate 0 to 72 mg/l (3), pH 8.3 to 9.3 (8.8), total phosphate 0.22 to 4.03 mg/l (1.43), sulphate 0.11 to 7.71 mg/l (3), total hardness 50 to 120 mg/l (76), DO 4.2 to 7.8 (6) and Fe 0.004 to 6.63 (3), respectively, in the Oussudu lake. In the present analysis higher values of CV were obtained for sulphate, iron, nitrate and total phosphate, which indicated greater variability of their concentration in the lake water.

Table 1: Basic Statistics of Oussudu lake water quality data

Statistics	pH	EC	DO	Alkalinity	TH	Ca	Mg	SO_4	Fe	NO_3	Cl	TP
N	94	94	94	94	94	94	94	94	94	78	94	56
Min.	8.3	200	4.2	73.4	50	4.812	8.068	0.11	0.004	0.005	14.29	0.22
Max.	9.3	290	7.8	112	120	12.832	25.272	7.71	6.63	72	29.99	4.03
Median	8.8	250	6	95.7	76	7.699	14.337	3.005	3.075	0.1	16.34	1.24
Mean	8.794	246	6.01	93.75	76.35	7.638	13.923	2.983	2.951	3.201	19.22	1.43
Std. Dev.	0.242	18.4	0.8	6.325	11.46	1.525	2.986	1.365	2.261	9.035	4.704	0.92
Variance	0.059	340	0.64	40	131.4	2.327	8.916	1.862	5.111	81.64	22.13	
C.V.	0.028	0.08	0.13	0.067	0.15	0.2	0.214	0.457	0.766	2.823	0.245	0.65

Principal Components Analysis

The PCA results are given in Tables 2 & 3. The results (Table 2) show that the first eigenvalue is equal to 4.156 and explained 34.634% of the variance in data set. The second and third eigenvalues are 2.539 and 1.582, which explained 21.608% and 13.183% of the total variances in the data set, respectively. Hence, it is evident that first three components explain about 69% of the total variance in the Oussudu lake water quality data having eigenvalues greater than "one", which generally used to explain dominance of principal component loadings.

The results (Table 3) of pre-rotated PCA, show that first component is highly loaded with magnesium, chloride, alkalinity, total hardness, pH, total phosphate and calcium, which could be related to geologic and anthropogenic factors of the lake catchment. Second component was found to heavily weighted on iron, sulphate and nitrate and could be due to leachate/effluent entry from industrial dumping sites as reported near the Oussudu lake from time to time (Selvanayaki, 1997). The lake Oussudu is a shallow water body and representing satisfactory levels of dissolved oxygen in the lake, which has been reflected in third component by high loadings of dissolved oxygen.

Table 2: Eigenvalues & variance explained by pre-rotated PCA

Vectors/ Components	Eigenvalues	% of total variance explained	Cumulative % of variance
1	4.156	34.63	34.63
2	2.593	21.61	56.24
3	1.582	13.18	69.42
4	0.822	6.849	76.27
5	0.680	5.666	81.93
6	0.662	5.516	87.45
7	0.457	3.808	91.26
8	0.396	3.3	94.56
9	0.248	2.066	96.63
10	0.229	1.908	98.53
11	0.176	1.467	100
12	0.000	0	100

Rotated Principal Components

In the present study, Kaiser's varimax technique was employed to chop off extraneous orthogonal axes (m-p unnecessary axes, where, p is orthogonal component axes in m space) in order to find better position for components (Davis, 1986). Kaiser's varimax scheme, which has as its objective the moving of each component axis to positions so that projections from each variable onto the component axes are either near the extremities or near the origin. The method operates by adjusting the component loadings so they are either near ±1 or near zero. For each component, there will be a few significantly high loadings and many insignificant loadings. Kaiser's varimax scheme, maximize the variance of loadings down through columns of the component loadings matrix. Maximizing the variance implies maximizing the range of loadings, which tends to produce either extreme (positive or negative) or near zero loadings, satisfying the purpose of rotation.

Table 3: Pre rotated PCA loadings of the Oussudu lake water quality

Variable	Eigenvectors				
	1	2	3	4	5
Magnesium	**0.864**	0.279	0.033	0.366	-0.044
Chloride	0.791	-0.077	-0.089	0.318	0.002
Alkalinity	0.759	0.123	0.389	-0.042	0.013
TH	-0.731	0.509	0.083	0.363	-0.134
pH	0.718	-0.068	-0.488	0.057	0.104
TP	0.648	-0.234	-0.063	0.267	0.076
Calcium	0.591	0.622	0.142	-0.096	-0.256
Iron	0.306	**0.714**	-0.457	0.110	-0.186
Sulphate	0.324	0.669	-0.040	0.321	0.321
Nitrate	-0.201	0.614	0.097	-0.302	0.589
EC	0.314	0.551	0.581	-0.204	-0.257
DO	-0.203	0.342	**0.773**	-0.349	-0.162

The results of rotated PCA are given in Tables 4 & 5. Retaining all components that have eigenvalues greater than one, 6 principal components are useful and explain the variability upto 87%. These are summarised as below:

(a) Total hardness factor (total hardness, magnesium, pH, alkalinity)
(b) Conductivity factor (electrical conductivity, calcium, alkalinity)
(c) DO factor (dissolved oxygen, iron)
(d) Sulphate factor (sulphate, alkalinity, calcium)
(e) Nitrate factor (nitrate)
(f) Phosphate factor (total phosphate, chloride)

Table 4: Eigenvalues and variance explained by rotated components

Vectors/ Components	Eigenvalues	% of total variance explained	Cumulative % of variance
1	2.763	23.028	23.028
2	1.982	16.520	39.548
3	1.619	13.491	53.039
4	1.553	12.938	65.977
5	1.065	8.876	74.853
6	1.512	12.600	87.453

Table 5: Rotated PCA loadings of the Oussudu lake water quality

Variable	Eigenvectors					
	1	2	3	4	5	6
TH	**0.931**	0.040	0.101	0.125	0.086	-0.221
Mg	0.929	-0.201	0.024	-0.008	0.085	-0.229
pH	-0.609	-0.103	0.311	0.356	-0.157	0.388
Alkalinity	-0.539	0.509	-0.301	0.419	-0.119	0.057
EC	0.033	**0.923**	-0.106	0.006	0.197	0.053
Ca	-0.210	0.766	0.223	0.397	-0.017	0.078
DO	0.017	-0.140	**0.909**	-0.037	0.095	-0.220
Fe	0.103	0.355	0.708	0.392	0.075	0.299
SO4	0.036	0.198	0.098	**0.880**	0.0197	0.044
NO3	0.165	0.153	0.119	0.164	**0.926**	-0.111
TP	-0.321	0.062	-0.087	-0.039	-0.030	**0.857**
Cl	-0.419	0.141	-0.039	0.344	-0.247	0.600

First rotated component, accounting for about 23% of the total variance, heavily weighted on Total Hardness, magnesium, negatively weighted with pH and alkalinity. High loading of total hardness could be associated with weathered of rocks and subsequent dissolution of ions in water. Second rotated principal component gives heavy weights to conductivity, calcium and alkalinity, accounting for about 17% of the total variance (Table 4). It may be interpreted as conductivity component, which indicates the dominance of soluble ions viz., calcium and alkalinity in lake water. Third principal component explains about 13% of the total variance is highly loaded on dissolved oxygen and iron. This component may be called as dissolved oxygen component, which is a most important parameter in lake study. Fourth rotated component heavily loaded on sulphate, alkalinity and calcium accounting for about 13% of the total variance. This component is called as sulphate component. Sulphate occurs naturally in water as a result of leaching from gypsum and other common minerals as well as in the form of oxidized stages of sulphides, sulphites, and thiosulphates, which are usually discharged into the system from natural or man-made sources. Dominance of sulphate and chloride may also be linked to entry of domestic/industrial effluents in the lake. Fifth rotated component heavily loaded on nitrate, accounting for about 9% of the total variance attributed to lake water due to application of nitrogenous fertilizers in the catchment. Sixth component explained about 13% of total variance in data set, was heavily weighted on total phosphate and chloride, which could also be treated as anthropogenic activities of the catchment (fertilizer, cattle grazing, domestic wastes, etc.)

CONCLUSIONS

The results of pre rotated PCA suggest dominance of magnesium, iron and DO factors with 69 % variation in data set. Whereas, PCA after varimax rotation is found to be most appropriate in describing the lake water quality of the Oussudu lake. Accordingly, six factors have been found useful in describing the water quality pattern in the Oussudu lake, which explained total variance upto 87%. These factors were designated as total hardness, conductivity, dissolved oxygen, sulphate, nitrate and total phosphate.

Therefore, from the present analysis it could be concluded that any water quality monitoring program of the Oussudu lake should atleast involve the monitoring of total hardness, conductivity, dissolved oxygen, sulphate, nitrate and total phosphate.

It would be interesting to extend the study to similar lakes of the region so as to evolve a regional pattern.

ACKNOWLEDGEMENT

The authors are grateful to Prof. S.A. Abbasi, Centre for Pollution Control and Energy Technology, Pondicherry University, Pondicherry (India) for his valuable advice and providing data generated by one of his Ph. D. students. The authors are also thankful to Dr. K.D. Sharma, Director, National Institute of Hydrology, Roorkee, for granting permission to submit this paper for the National Seminar.

REFERENCES

Chari, K.B. and Abbasi, S.A. 2005. A study on the fish fauna of Oussudu-a rare fresh water lake of South India, Intl. J. Env. Studies, Vol. 62, No. 2, pp. 137-145.

Chari, K.B., Abbasi, S.A. and Ganapathy, S. 2003. Ecology, habitat and bird community structure at Oussudu lake: towards a strategy for conservation and management, Aquatic Conservation: Marine and Fresh Water Ecosystems, Vol. 13, No. 5, pp. 373-386.

Davis, J.C. 1986. Statistics and data analysis in geology (2nd Ed.). *John Wiley & Sons, New York.*

Deverel, S. J. (1989) Geo-statistical and principal components analysis of ground water chemistry and soil salinity data, San Joaquin Valley, California. Proc. of Baltimore Symposium, May 1989, Regional Characterisation of Water Quality, *IAHS Publ. 182, pp. 11-18.*

Melloul, A. & Collin, M. (1992) The 'Principal Components' statistical method as a complementary approach to geochemical methods in water quality factor identification, application to the Coastal Plain aquifer of Israel. *Elsevier Science Publishers B.V. Amsterdam, 49-73 pp.*

Rao, S.V. L. (2001) Principal components of ground water quality in Venkatagiri taluq, Nellore district, A.P., India. *Hydrology Journal, 24 (3), 49-54.*

Selvanayaki, J. 1997. Some limnological studies on Oussudu lake, M. Phil. Thesis, Centre for Pollution Control & Energy Technology, Pondicherry (Central) University, Pondicherry, India.

Vajrappa, H C & Srinivas, G. (1994). Hydrogeochemistry of kabini river basin in Karnataka. In: *Regional Workshop on Environ. Aspects of Ground Water Dev.,* Oct. 17-19, 1994, Department of Geology, Kurukshetra University, Kurukshetra, India.