------ Raf. Jour. Sci., Vol. 16, No. 1 Geology, Special Issue, pp.56-64, 2005 ------

Application of Factor Analysis as a Tool for Water Quality Management of Tigris River within Mosul City

Sati M. Al-Rawi **Abdulmuhsin S. Shihab**
Research Centre for Environment and Water Resources
Mosul University

(Received 16/2/ 2003 , Accepted 27/7/ 2003)

ABSTRACT

This paper focuses on the utilization of factor analysis as a tool for water quality management. Factor analysis has the ability to reduce a large number of variables and identify a set of dimensions, which can not be easily observed in a large set of variables. Bimonthly water samples were collected along Tigris river within Mosul city from Sept 1999 to Aug 2000. Samples were tested for (16) chemical, physical and biochemical parameters. Factor analysis extracted five factors, which explain more than 83% of the variation in water quality. The results of the rotated factor loadings showed that rock dissolution has the maximum contribution in water quality variation. The other sources, which were noticed from the results of the analysis, were runoff, seasonal variations, industrial and domestic discharges. They contributed -at variable degrees- to such variation. The study also concluded that factor analysis technique is an efficient tool for water quality management agencies.

استخدام التحليل العاملي كاداة لادارة نوعية مياه نهر دجلة في مدينة الموصل

الملخص

ركز البحث الحالي على الاستفادة من طريقة التحليل العاملي كاداة في ادارة نوعية المياه. تمتاز هذه الطريقة بقابليتها على تحليل كمية كبيرة من البيانات وتقليص عدد المتغيرات واظهارها بشكل عوامل مؤثرة. تم جمع عينات من مياه نهر دجلة من مقطعه الذي يجري في مدينة الموصل في مواقع مختارة واجريت عليها الفحوصات الكيمياوية والفيزياوية والبايوكيميائية وبواقع 16 فحص للمدة من ايلول 1999 ولغاية آب 2000. استخلص التحليل العاملي خمسة عوامل مسؤولة عن اكثر من 83% من التباين في نوعية المياه في منطقة الدراسة. كان ذوبان الصخور في المرتبة الاولى في مشاركته في تغير نوعية المياه. كما اظهرت نتائج التحليل مشاركة مياه السيل السطحي والتغيرات الموسمية والفضلات الصناعية والمنزلية وبنسب متفاوتة في هذا التغير. واستنتج البحث ان التحليل العاملي هو أداة كفوءة ونافعة لمنظمات ادارة نوعية المياه.

INTRODUCTION

Knowledge of water quality plays significant role in the development, control and management strategies of water resources. For water quality management, it is important to identify the sources of pollution or the source of water quality variation.

The main reason for the assessment of water quality is to verify whether the observed quality is suitable for intended use. This necessitates conducting a thorough survey to determine trends in water quality and how it is affected by the release of contaminants. Such survey will comprise data collection, evaluation, and reporting.

As water quality involves many parameters, the monitoring produces a large amount of data. To reduce this data into a smaller set, statistical analysis methods may be applied.

Factor and principal component analyses are techniques useful for reducing a large number of variables and identify a set of dimensions which can not be easily observed in the large set of variables (Legndre and Legndre, 1979). Many researchers in the world have used principal component or factor analysis in water quality management Lohani and Todino (1984) in Thailand, Neilson and Stevens (1985), Simoneau (1986) and Esterby *et al*. (1989) in Canada, Mohammed (1988) Dawood (1989) and Shihab (1993), Borovec (1996) in USA, Wu *et al*. (2000) in Taiwan, Martos *et al*. (2001) in Spain and Reinikainen *et al*. (2001) in Finland.

In Mosul city, Tigris river is the sole water source. Despite the bigness of the city (with more than one million dwellers) but it lacks the presence of a central wastewater treatment plant. The river supports a wide variety of activities including water supply. Wastes resulting from different activities reach Tigris via sewers without any treatment process. Progressive urbanization and industrial development increased waste disposal activities. The pollution arising from these and other sources has led to the increasing need for vigorous assessment of the river water quality.

Many other factors contribute to the variation in Tigris river water quality. These include Mosul dam operation, seasonal variation, geological formation and runoff.

This research try to reduce the dimensions of water quality, identify the source of water quality variation and pollution by using factor analysis method on a large data of water quality parameters of Tigris river within Mosul city.

MATERIALS AND METHODS

Nine sites were selected on a stretch of 20 km along the river. The sampling sites are shown in Fig.(1). Bimonthly samples were collected for one-year interval from September 1999 to August 2000.

Various physical and chemical as well as biochemical tests had been conducted on each sample (temperature, dissolved oxygen, pH, electrical conductivity, BOD, turbidity, chloride, alkalinity, calcium, magnesium, potassium, sodium, total solids, total dissolved solids, suspended solids and sulphate). These tests were performed as per procedures outlined in the standard methods for the examination of water and wastewater (APHA, 1992).

The collected data were statistically analyzed using the software SPSS program. The raw data were standardized as water quality parameters have different magnitudes and scales of measurements (Legndre and Legndre, 1983). This type of ordination reduce the dimensionality of the data set and minimize the loss of information caused by the reduction (Simoneu, 1986).

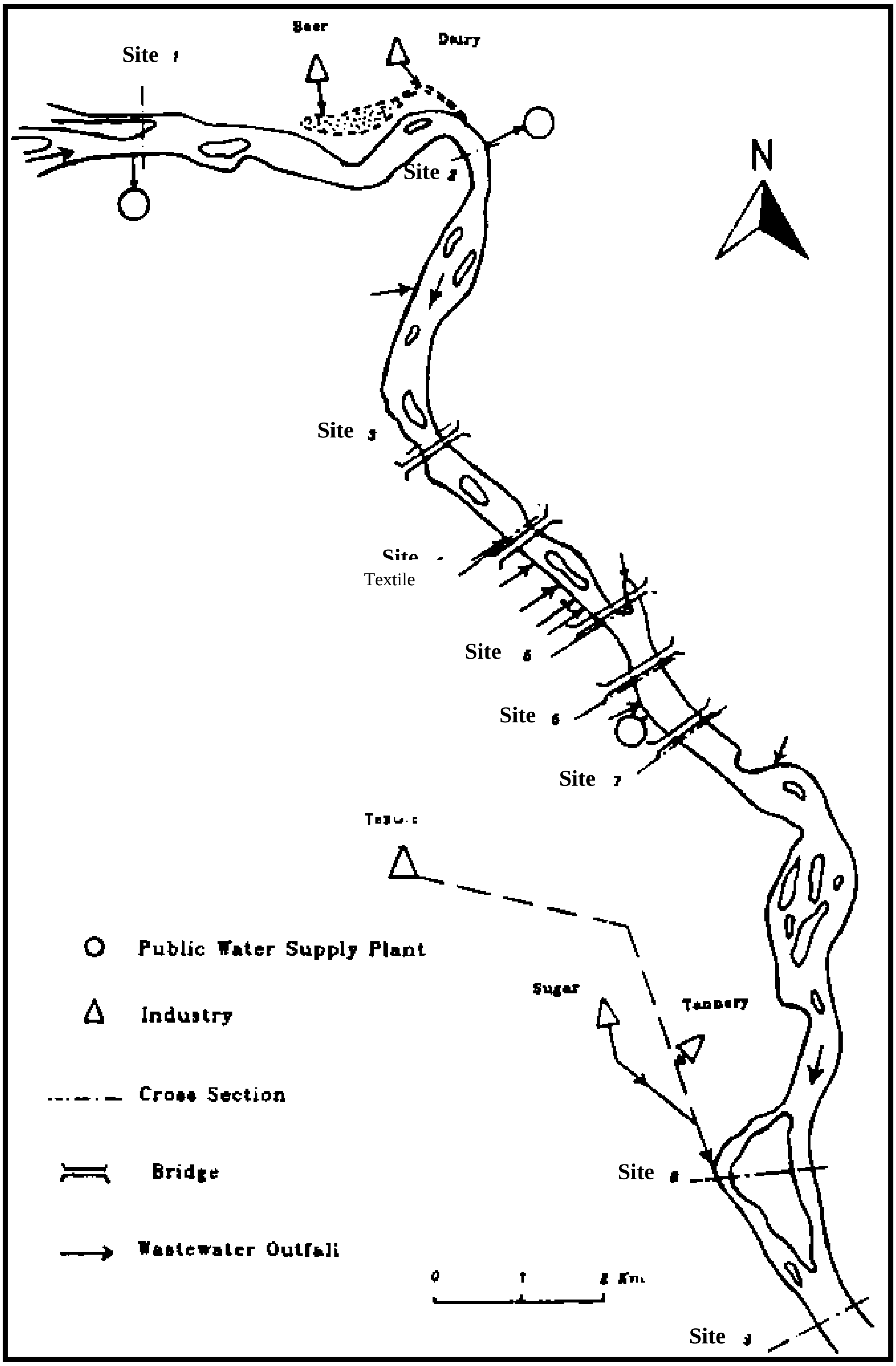

Fig. 1: Locations of selected sites along Tigris river within Mosul city.

Factor analysis was conducted on standardized data. The method used the correlation matrix of observation (X) to estimate a sorted matrix of eigenvalues (λ) and corresponding eigenvectors (factor loading V). The characteristic equation is $[X-\lambda I]\,V=0$, where each eigenvalue λ is associated with an eigenvector V. The factors with eigenvalues equal to or greater than one are retained using Kaiser criterion (Davis, 1973). Varimax rotation was used to yield a simpler factor structure (Kaiser, 1958). The factor matrix loadings, obtained from the analysis, were projected in a reduced plane formed by the first factor and with the other factors individually. Also the origocentered equilibrium circle, which denotes the 95% confidence level, was drawn. The variables (descriptor axis) projected outer the circle is significantly correlated with the nearest factor. In addition, the angle between the descriptor axes or between a descriptor axis and a factor represents the correlation between variables or between a variable and a factor (lower values of angles mean high correlation, right angle means zero correlation).

RESULTS AND DISCUSSIONS

The statistical descriptions of the measured water quality parameters (mean, standard deviation, minimum and maximum values) are listed in table (1).

Factor analysis extracted five factors with eigenvalues greater than (1) that account for more than 83% of the variance of water quality, i.e., the 16 variables were concentrated into 5 factors. Eigenvalues, communalities, percentage of variance and their loadings are shown in table 2. The communalities represent the index of efficiency to reduced set of factors. The lower communality was for potassium (0.613).

For factor loadings the values which are greater than the radius of the equilibrium circle of contribution (Radius=(No. of extracted factors/No. of variables)$^{0.5}$ = $(5/16)^{0.5}$ = 0.559) are considered significant.

Factor I accounts for 25.71% of the variance in water quality of Tigris river within the study area. It represents the dissolution of rocks which is reflected on EC, Ca^{++}, K^{+}, Na^{+}, and $SO_4^{=}$ ions concentration (table 2). The formation of Mosul dam lake in the north of the study area is responsible for the increasing effects of gypsum rock dissolution. The variation in conductivity and the aforementioned ions is agreed with the study of Shihab (1993) which conducted PCA on that water body.

These results reveal that sulphate as anion, calcium, potassium and sodium as cations constituted the ion strength of Tigris river water. These variables are significantly correlated with each other (Fig. 2). This factor is also dominated by dissolved oxygen and biochemical oxygen demand. The latter represent the influence of domestic wastes discharged-untreated to Tigris river, i.e. the discharge of domestic wastes in the river increases BOD, which consume dissolved oxygen in the degradation by bacteria.

Table 1: Statistical description for measured water quality parameters.

	Parameters	Mean	SD	Min.	Max.
T	Temperature °C	15.08	4.37	8.30	21.00
DO	Dissolved oxygen (mg/l)	8.04	1.03	6.00	9.80
pH	pH	7.98	.37	7.50	9.50
EC	Electrical conductivity (μmos/cm)	451.05	116.82	281.00	849.00
BOD	Biochemical Oxygen Demand (mg/l)	2.20	1.83	0.15	7.25
Turb	Turbidity (ntu)	19.30	10.21	4.00	52.00
Cl	Chloride (mg/l)	25.66	7.36	13.00	45.00
Alk	Alkalinity (mg/l)	142.07	21.47	78.00	218.00
Ca	Calcium (mg/l)	68.20	16.21	53.00	129.10
Mg	Magnesium (mg/l)	9.16	4.21	2.50	19.20
K	Potassium (mg/l)	3.29	1.12	2.25	7.95
Na	Sodium (mg/l)	10.87	3.03	3.80	19.00
TS	Total solids (mg/l)	311.77	94.41	194.00	568.00
TDS	Total dissolved solids (mg/l)	248.00	81.74	134.00	417.00
SS	Suspended solids (mg/l)	61.13	70.72	13.00	276.00
SO_4	Sulphate (mg/l)	77.18	36.96	31.00	204.00

Table 2: Rotated factor loadings, communalities, eigenvalues and percentage of variance for Tigris river water quality parameters within Mosul city (significant loadings are bolded).

Parameters	Factors					Communality
	I	II	III	IV	V	
Temp	-0.123	**-0.905**	-0.117	0.208	-0.225	0.942
DO	**0.600**	0.194	0.483	-0.421	0.129	0.824
pH	-0.072	**0.748**	0.363	-0.442	-0.156	0.916
EC	**0.868**	-0.044	0.333	-0.174	-0.052	0.900
BOD	**0.583**	-0.184	0.110	**0.661**	-0.032	0.824
Turb	-0.135	0.307	**0.829**	-0.004	-0.213	0.846
Cl	-0.027	-0.077	-0.071	**0.913**	-0.061	0.849
Alk	-0.032	-0.032	-0.062	0.113	**0.924**	0.873
Ca	**0.799**	0.318	0.200	0.128	0.229	0.849
Mg	0.190	-0.509	-0.391	0.265	-0.447	0.718
K	**0.775**	-0.004	-0.110	-0.004	-0.020	0.613
Na	**0.739**	-0.093	-0.154	0.182	-0.188	0.647
TS	0.328	0.445	**0.709**	-0.062	0.213	0.858
TDS	0.222	-0.222	**0.867**	-0.065	0.325	0.960
SS	0.179	**0.891**	-0.036	0.166	-0.178	0.886
SO_4	**0.781**	0.213	0.185	0.427	-0.046	0.874
Eigenvalue	4.114	3.010	2.717	2.068	1.471	
% Variance	25.712	18.810	16.981	12.924	9.193	
% Cumulative	25.712	44.522	61.504	74.427	83.620	

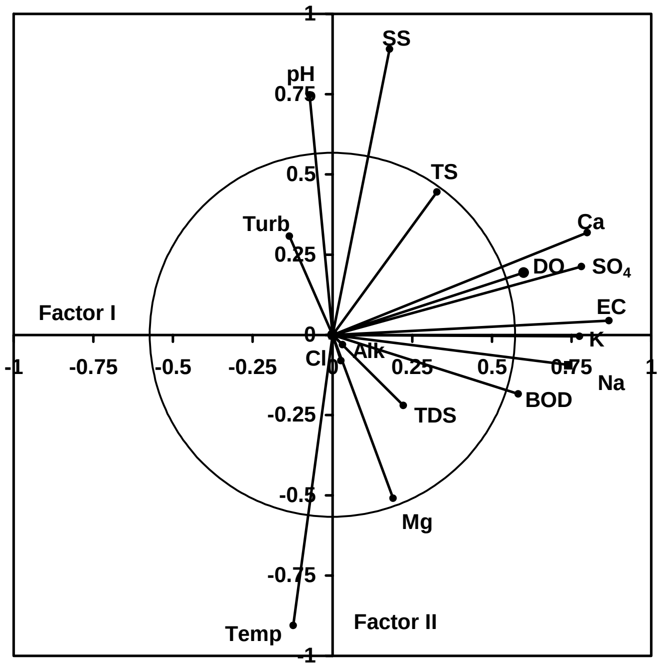

Fig.2: Correlations of water quality parameters with Factor I and II with 95% confidence level origocentered circle.

Factor II accounts for 18.81% of the variance in water quality. It is dominated by temperature (T), suspended solids (SS), and hydrogen ion concentration (pH). This factor represents the seasonal influence in water quality which include thermal inversion in Mosul dam lake. The variation in temperature, the type of eroded soil (SS) and the utilization of CO_2 by algae in the photosynthesis affects on pH (Kiely, 1997). Figure (2) shows that temperature has a significant inverse correlation with suspended solids and pH.

On the other hand, factor III accounts for 16.98% of the variance in water quality. It is dominated by turbidity (Turb), total solids (TS), and total dissolved solids (TDS). This emphasizes that the colloidal fraction (as dissolved) of water constituting water turbidity as the river water source is Mosul dam lake. The runoff from catchement area also contribute in the variation in turbidity, total solids and total disolved solids. These parameters are also significantly correlated to each other (Fig. 3).

Table (2) shows that factor IV accounts for 12.92 % of the variance in water quality. It is dominated by the biochemical oxygen demand (BOD) and chlorides (Cl^-). Again the parameters are significantly correlated to each other (Figure 4). Chloride is one of the constituents of organic wastes, therefore it is used as an indication of contamination with organic wastes (Kiely, 1997). This factor indicates the domestic and industrial pollution effects on the Tigris within the study area.

Factor V accounts for 9.19% of the variance in water quality. It is dominated by alkalinity only (Fig. 5). Alkalinity is associated with bicarbonate from natural formations, or perhaps from industrial and municipal waste discharges.

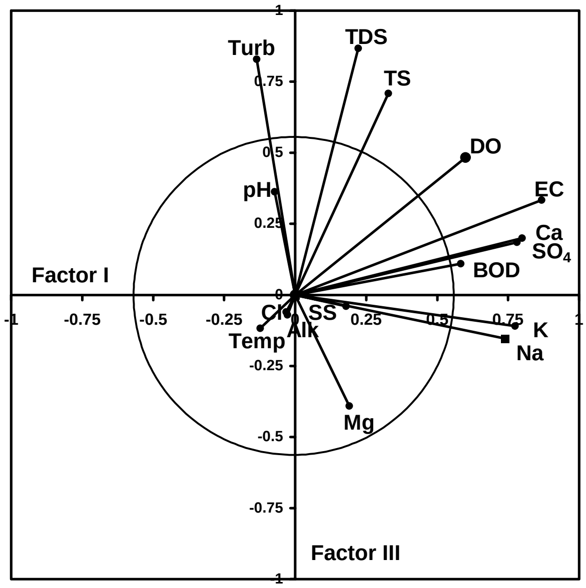

Fig.3: Correlations of water quality parameters with Factor I and III with 95% confidence level origocentered circle.

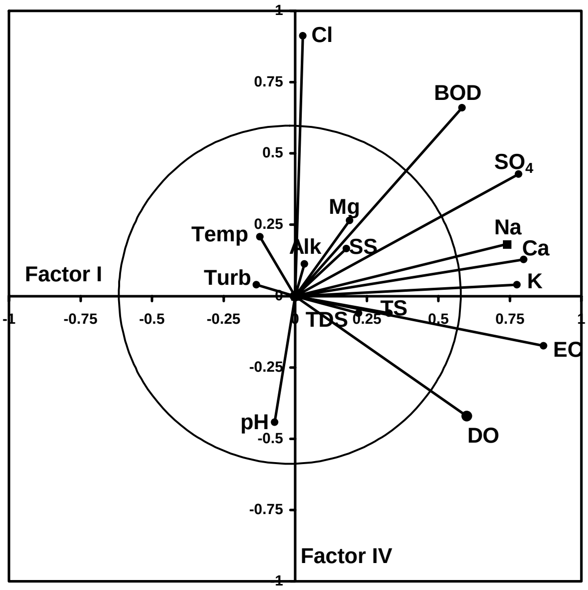

Fig.4: Correlations of water quality parameters with Factor I and IV with 95% confidence level origocentered circle.

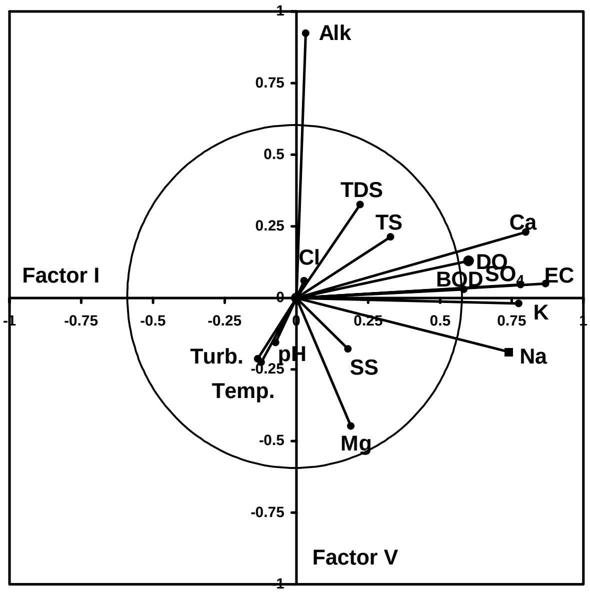

Fig.5: Correlations of water quality parameters with Factor I and V with 95% confidence level origocentered circle.

CONCLUSIONS

From the results of factor analysis, it appears that such type of analysis has identified the sources of water quality variations in the study area. Such variation cannot be easily detected in a large set of data. This shows the importance of such technique for water quality management agencies.

Factor analysis explained 83.62 % of variation in water quality in five factors. From the results of this analysis, it is seen that rock dissolution, runoff, seasonal variations, industrial and domestic discharges are all contributing -to different degrees- to such variations.

REFERENCES

APHA, AWWA and WPCF 1992. Standard Method for the Examination of Water and Wastewater. 18th ed., APHA, Washington, DC.

Borovec, Z., 1996. Evaluation of the concentrations of trace elements in streams sediments by factor and cluster analysis and the sequential extraction procedure. Sci. Total Environ. 177, pp.237-250.

Davis, J.G., 1973. Statistics and data analysis in geology. John Wiely and Sons, Inc. New York, pp. 473-524.

Dawood, D.M., 1989. Trace elements in Tigris river and their impact on drinking water. M.Sc. thesis, College of Engineering, Mosul University.

Esterby, S.R., El-Shaarawi, A.H., Howell, G.D. and Clair, T.A., 1989. Spatial characterization of acidification related parameters in sensitive regions of Atlantic, Canada. Water, Air and Soil Pollution, 46, pp.289-303.

Kaiser, H.F., 1958. The varimax criterion for analytic rotation in factor analysis. Pyrometrical, 23, pp.187-200.

Kiely, G., 1997. Environmental Engineering. Irwin McGraw-Hill, UK, p.59, 219.

Legendre, L. and Legendre, P., 1979. Ecologie numerique Tome2: la structure des donnees ecologiques. Press de l Universite du Quebec, Masson, Paris, (in French), (Cited by Simoneau).

Legndre, L. and Legndre, P., 1983. Numerical Ecology: Developments in Environmental Modeling 3. Elsevier, Amsterdam, 419p.

Lohani, B. and Todino, G., 1994. Water quality index for Chao Pharya river. J. Environ. Engg. Div. ASCE, 110(6), pp.1163-1176.

Martos, F.S., Espinosa, R.J. and Bosch, A.P., 2001. Mapping groundwater quality variables using PCA and geostatistics: a case study of Bajo Andarax, southeastern Spain. Hydro. Sci. J. des Sci. Hydrologiques., 46(2), pp.227-242.

Mohammed, A.B., 1988. Effect of Tigris river water quality on the performance of water treatment plants. M.Sc. thesis, College of Engineering, Mosul University.

Neilson, M.A. and Stevens, R.J.J., 1986. Determination of water quality zonation in lake Ontario using multivariate techniques. Proceedings of the Workshop held at Canada Centre of Inland Waters. Oct 7-10, Elsevier Science Publishers, 27, pp.99-116.

Reinikainen, S.P., Laine, P., Minkkinen, P. and Paatero, P., 2001. Factor analytical study on water quality in lake Saimaa, Finland. Fresenius J. Analy. Chem., 369, pp.727-732.

Shihab, A.S., 1993. Application of multivariate methods in the interpretation of water quality monitoring data of Saddam Dam Reservior. Confidential, SRCD, Mosul University.

Simoneau, M., 1986. Spatial variability in the water quality of Quebic rivers. Proceedings of the Workshop held at Canada Centre of Inland Waters. Oct 7-10, Elsevier Science Publishers, 27, pp.117-135.

Wu, J.T., Chang, S.C., Wang, Y.S., Wang, Y.F. and Hsu, M.K., 2001. Characteristics of the acidic environment of the Yuanyang lake (Taiwan). Bot. Bull. Acad. Sin., 42, pp.17-22.