CHINESE GEOGRAPHICAL SCIENCE
Volume 6, Number 4, pp.364–374, 1996
Science Press, Beijing, China

DYNAMIC VARIATIONS OF WATER QUALITY IN TAIHU LAKE AND MULTIVARIATE ANALYSIS OF ITS INFLUENTIAL FACTORS

Cai Qiming(蔡启铭)　Gao Xiyun(高锡芸)
Chen Yuwei(陈宇炜)　Ma Shengwei(马生伟)
Nanjing Institute of Geography and Limnology, the Chinese Academy of Sciences, Nanjing 210008, PRC
Martin Dokulil
Institute of Limnology, Austria
(Manuscript was received in March 1996)

ABSTRACT: Dynamic variation of water quality in Meiliang Bay and part of western Taihu Lake has been analysed based on the data from 1991 to 1992. Principal component analysis is used to reveal the mutual relationships of various factors. It is shown that there exists an obvious spatial and temporal variation in the main factors of water quality. Annual values of TP, TN, CON, Chl-a and conductivity decrease evidently from inner Meiliang Bay to the outer from north to south. TP and TN fluctuate seasonally with much higher value in winter. This is particularly true for the mouth of the Liangxi River. In addition, the Chl-a has a synchronous variation with water temperature, although being lagged a little, and closely relates to TP and TN. Finally, the results from principal component analysis show that TP, TN, SS (or SD), water temperature and Chl-a are the most influential factors to water quality in this area, and both suspensions and algae can contribute to transparency in Taihu Lake.
KEY WORDS: Taihu Lake, dynamic variation of water quality, principal component analysis

Taihu Lake is a large shallow lake in China , which plays an important role in water quantity regulation, water supply, cultivation, etc. With the rapid development of agriculture and industry in the area , a large number of pollutants have been discharged into the lake , leading to an increase of nutrients salts and occurrence of algae bloom as well as deterioration of ecological states. Thus, it has great significance to monitor and analyse the water quality and dynamic characteristics of the lake in detail, to make a deep research on the formation of eutrophication and to predict the water environment of the lake. By using the monitoring data obtained from 1991 to 1992, this article attempts to analyse the spatial and temporal variation of various water quality factors, to discuss the effects of the major factors on the lake environment and their mutual relations by means of multivariate analysis method.

I. MONITORED WATERS

The monitored area includes Meiliang Bay and part of western Taihu Lake region. Meiliang Bay located at the north of Taihu Lake is the main water supply source of Wuxi City, connects with the Liangxi and the Zhihugang rivers. Due to the influences of the cities and rivers surrounding the lake, Meiliang Bay is one of the major eutrophic waters of the lake.

Ten sampling points are chosen from north to south in the area(Fig. 1). From October 1991 to October 1992, sampling was made twice every month, involved more than 20 items of physical, chemical and biological factors.

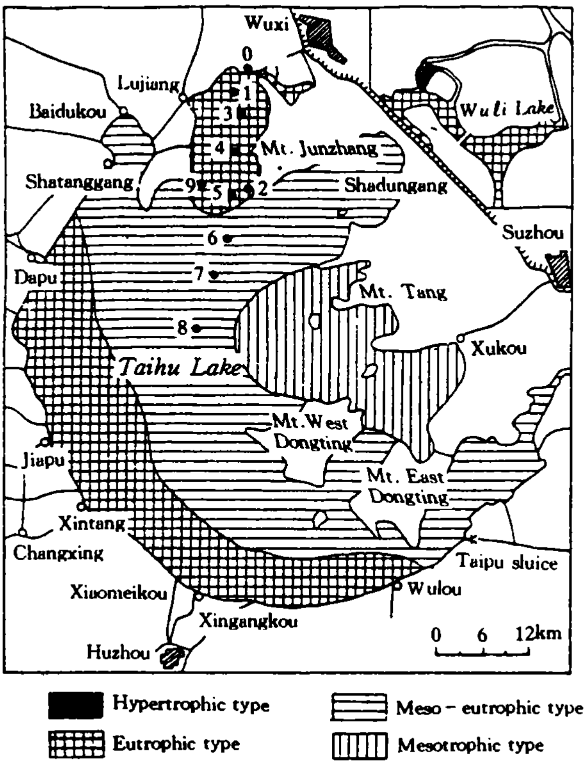

Fig. 1 Monitored water area and sampling points

II. RESULTS AND DISCUSSION

1. Temporal and Spatial Variation of Main Water Environment Factors

The annual mean values of several main factors of water quality are given in Fig. 2. It is found that COD, TP, TN, Chl-a and conductivity all decrease evidently from the inner to the outer of the bay along the line from north to south, only pH at point No. 4 is higher. The water quality observed at the sampling points No. 6, 7 and 8, all the outside points of the bay, has the states of lake center is similar to each other. In Fig. 2, the vertical lines express annual standard deviation. Generally, it is larger in the inner bay than the outer. Evidently, the water quality in the bay is worse than the center of the lake due to the effect of discharge from Wuxi City. It may be concluded that the diffusion and the dilution function of water is an important process of self-purification in the bay.

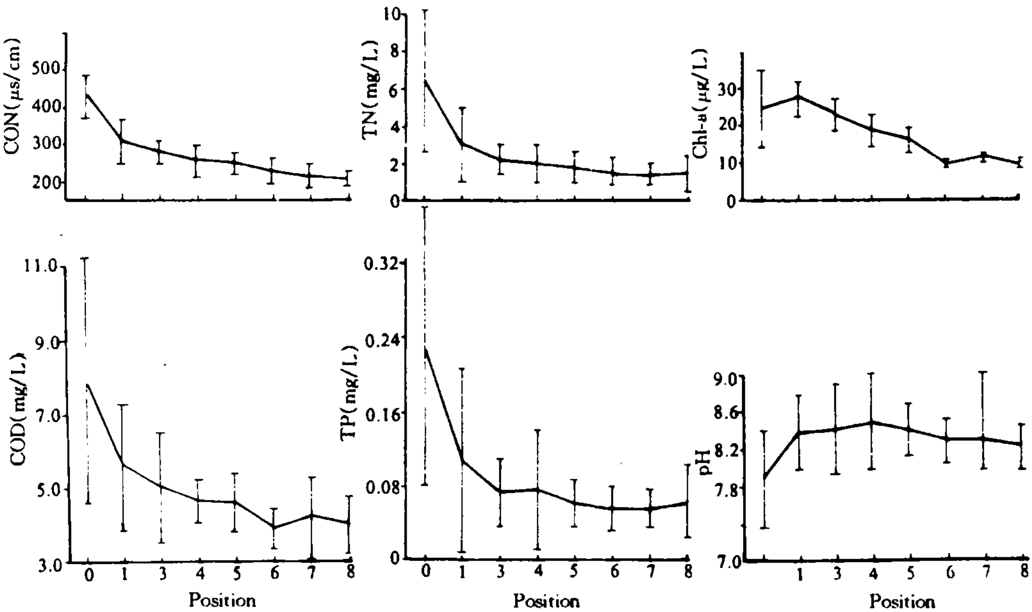

Fig. 2 Variation of annual mean values of main water quality factors with sampling points

Fig. 3 shows three-dimensional charts of concentrations of both TP and TN varying with month (time) and between sampling points (space), giving more marked characteristics of temporal and spatial variation. Temporally, the values of both TP and TN are obviously higher in winter than in summer. For instance, as high as 0.7 mg/L of TP and 1? mg/L of TN at point No. 0, the mouth of the Liangxi River, were measured in December 1991, while the corresponding values were only 0.06 mg/L and 2.2 mg/L in June 1992. Usually, the Liangxi River's water flows from the lake to Wuxi City, but inverse current is often found, especially in winter when the lake water level is so low that more water of the river flows from the city into Taihu Lake and, thus, pollutants from the city are more easily discharged into the lake. Naturally the river's mouth has higher concentrations of both nitrogen and phosphorus.

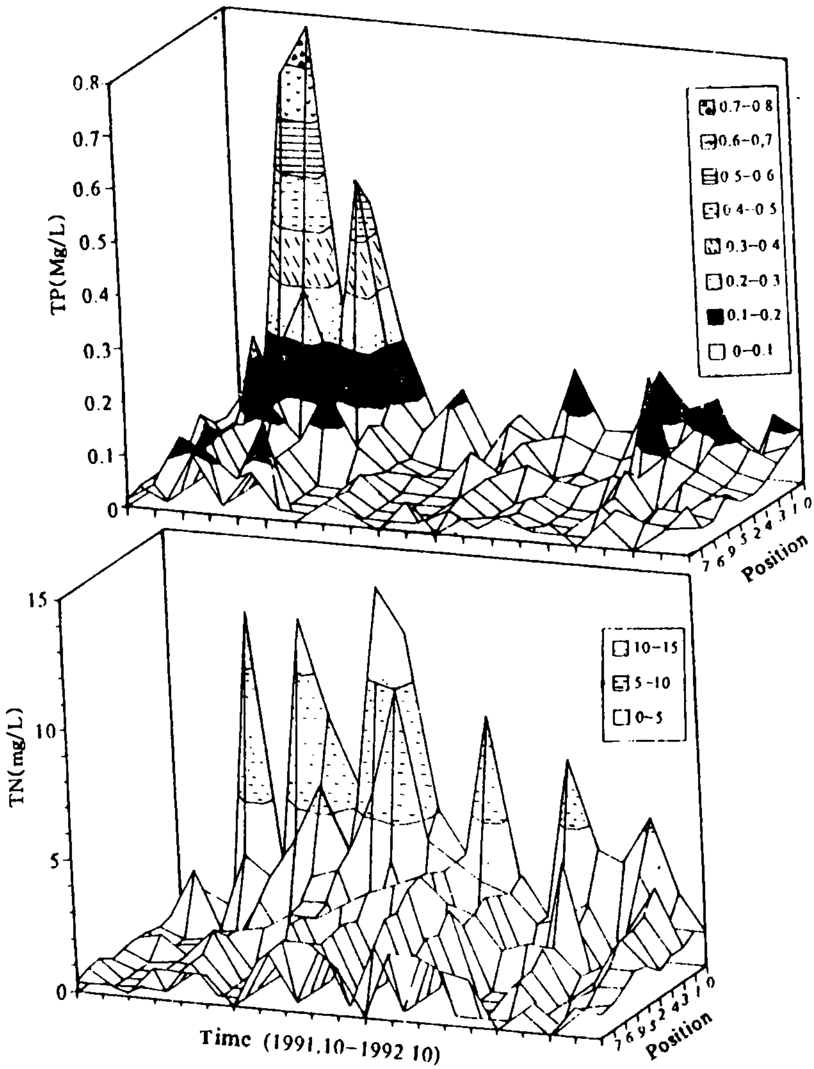

Fig.3 3-D dynamic variation of TP and TN from Oct. 1991 to Oct. 1992

For clearly showing the temporal variation, Fig. 4 is plotted choosing the sampling points No. 0, 1 and 8. It can be seen that both TP and TN at the point No. 0 have strong monthly fluctuations, and close relation to each other. To the mean value from November to December 1991, there existed an obvious high-value season for TP, the value declines sharply and remains relatively low from spring, through summer to fall. As for TN, its mean value keeps on a high level in spring and summer. It has an obvious decrease only after May. As for points No. 1 and 8, the above expression is not evident . Since point No. 0 lies at the mouth of the Liangxi River which is greatly influenced by the city's discharge, the fluctuation of TP and TN indicates the state of pollutant's discharge to certain degree. As point No. 8 is located in the center of the lake, far away from the mouth of the rivers , the values of water quality can be considered as the background of Taihu Lake while analysing the water quality characteristics of Meiliang Bay.

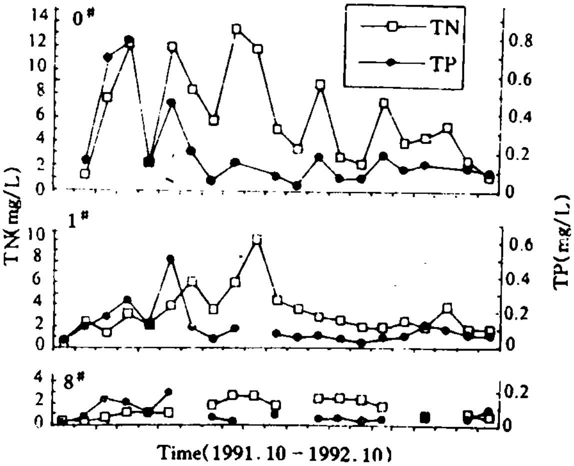

Fig.4 Temporal variation of TP and TN at points No. 0, 1 and 8

Fig. 5 shows the temporal variation curves of both SS (solid suspensions) and SD (transparency). It can be seen that there exist fluctuations, but with different variation phases. This is due to the wind and wave and boats in the lake, which lead to suspensions enrichment and transparency decline. It is different from deep lakes, suspensions in Taihu Lake is an important factor effecting transparency.

Fig. 6 shows the temporal variation of Chl-a content at the point No. 0, 1 and 8. The black dots represent the measured temperature. Comparing TP and TN , the strong fluctuations can also be seen, but the variation tendency is different from them. For the points No. 0 and 1, Chl-a content is larger in summer than in winter and the general trend of annual variation is parallel but a little lagging in time in comparison with that of water temperature. In winter and spring, the lower value period, it declines from 25 μg/L to some 5 μg/L, the minimum occurs from March to April. After April until September, the Chl-a value increases constantly. In summer, the value vibrates around 30 – 35 μg/L. With a little difference for point No. 8, which is located in the center of the lake , the Chl-a content is not remarkable higher in summer than in winter and spring. The value varies around 10 μg/L except from October to December and the trend of variation does not vary with water temperature.

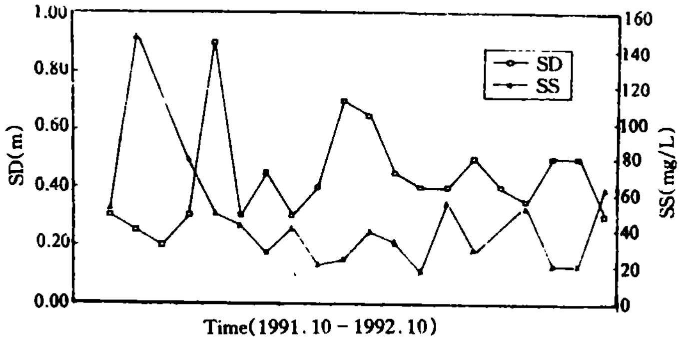

Fig. 5 Seasonal variation of SS and SD at point No.0

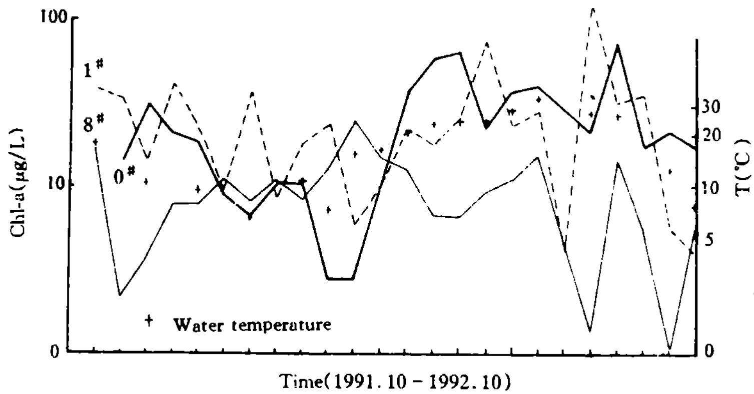

Fig. 6 Monthly variation of Chl-a and *Tw* at point No.0, 1 and 8

The relationship of Chl-a and TP is shown in Fig.7. The dots on Fig.7 (a) scatter about, the correlation coefficient is only 0.1 – 0.2. Nevertheless, the annual mean value at each sampling point has shown higher correlation and the correlation coefficient reaches 0.76, except for the point No.0(see Fig.7(b)). The latter has very high TP concentration without corresponding increase of Chl-a content, reflecting the feature of river mouth with pollutants discharge.

2. Principal Component Analysis

From the proceeding analysis of only a few factors , it can be found that we face a complex problem that is concerning different factors change constantly with temporal and spatial variation. Multivariate analysis is useful in revealing the connections and functions of environmental elements, among which the principal component analysis is one of the most important methods.

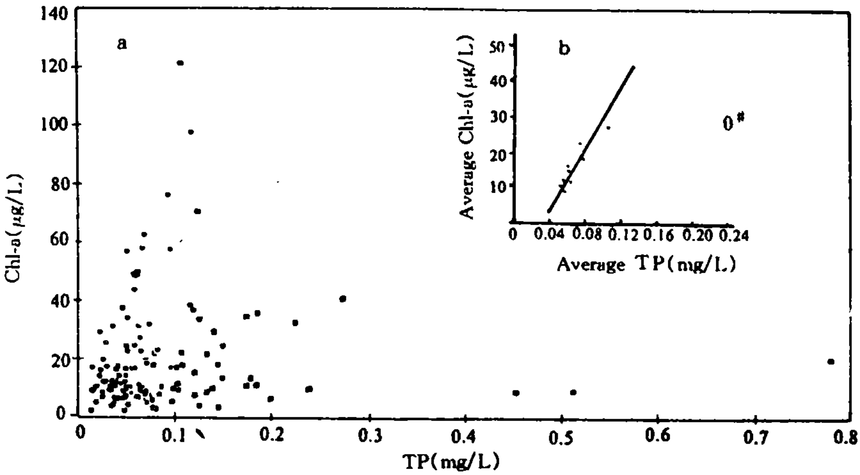

Fig.7 Relationship between Chl-a and TP

What was measured is a data matrix of environmental elements, varying with time and space. The purpose of principal component analysis is to synthesize the information included in the matrix by a certain optimum method so as to simplify the matrix and reduce the dimensions to reveal its structure as well as to give out reasonable interpretation and answer the problems.

Mathematically, fix a certain variable (for example, space), let rows and columns variables represent environmental factors and time respectively, the monitored one-year data forms a sample matrix:

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ \cdots \\ x_m \end{bmatrix} = \begin{bmatrix} x_{11} & x_{12} \cdots x_{1n} \\ x_{21} & x_{22} \cdots x_{2n} \\ \cdots\cdots & \cdots\cdots \\ \cdots\cdots & \cdots\cdots \\ x_{m1} & x_{m2} \cdots x_{mm} \end{bmatrix}$$

Principal component analysis is to find out a matrix V to form a new matrix Z by linear combination of V and X:

$$Z = \begin{bmatrix} z_1 \\ z_2 \\ \cdots \\ \cdots \\ z_m \end{bmatrix} = \begin{bmatrix} v_{11} & v_{12} \cdots v_{1n} \\ v_{21} & v_{22} \cdots v_{2n} \\ \cdots\cdots & \\ \cdots\cdots & \\ v_{m1} & v_{m2} \cdots v_{mn} \end{bmatrix} \begin{bmatrix} x_1 \\ x_2 \\ \cdots \\ \cdots \\ x_m \end{bmatrix}$$

The new variable matrix Z, which is the principal component, must meet the following two conditions: (1) new variables $Zi(i=1,2,....m)$ are independent from each other; (2) new variables reflect total variance of the m original variables as maximally and densely as possible. In such a way the original variables are described by new variable with less number. The percentage of contribution of first k principal is: component is:

$$C(k) = \sum_{i=1}^{k} \lambda_i / \sum_{i=1}^{m} \lambda_i$$

where $\lambda_i(i=1,2,...., m)$ are corresponding characteristic values of vector V. The method to obtain the matrix V may see the literature [3]. The following gives only the computed results.

Tables 1,2,3 show the results from the principal component analysis for one-year data at the sampling points No.0,4 and 6 , which represent river mouth, inner bay and outer bay. From Table 1 it can be seen that TP－TN, TP－CON (CON means conductivity), pH－Chl-a, TN－CON and Chl-a－*Tw* all have higher positive correlation and TP－SD, SS－SD, and pH－TN are all correlated negatively. In view of the coefficients of principal component, which represent contribution of

Table 1 Results of the principal componots analysis at point No.0

Correlation coefficients

	TP	pH	TN	SS	CON	Chl-a	SD	*Tw*
TP	0.1							
pH	−0.32	1.0						
TN	0.64	−0.06	1.0					
SS	0.27	−0.06	−0.27	1.0				
CON	0.75	−0.48	0.88	−0.25	1.0			
Chl-a	−0.05	0.53	−0.41	−0.13	−0.03	1.0		
SD	−0.51	−0.04	−0.10	−0.64	−0.17	−0.05	1.0	
Tw	−0.33	0.37	−0.40	−0.35	−0.15	0.64	0.4	1.0

Contribution of Various principal components

Principal component		1st	2nd	3rd
Characteristic value		3.36	1.95	1.54
Accumulative contribution rate		0.42	0.66	0.86
Coefficients of principal component	TP	0.43	−0.38	0.48
	pH	−0.09	−0.15	0.29
	TN	0.40	0.29	0.09
	SS	−0.05	0.71	0.19
	CON	0.57	0.41	−0.03
	Chl-a	−0.22	0.10	0.22
	SD	0.52	−0.27	−0.29
	Tw	−0.04	0.01	−0.72

Table 2 Results from principal component analysis at the sampling point No.4

Correlation coefficients

	TP	pH	TN	SS	CON	Chl-a	SD	*Tw*
TP	1.0							
pH	0.32	1.0						
TN	0.11	0.30	1.0					
SS	0.13	0.0	0.31	1.0				
CON	0.15	−0.12	0.13	−0.17	1.0			
Chl-a	−0.58	0.78	0.63	0.29	−0.15	1.0		
SD	−0.48	−0.27	−0.27	−0.79	0.30	−0.63	1.0	
Tw	0.11	0.86	−0.43	−0.10	0.27	0.59	0.0	1.0

Contribution of Various principal components

Principal component		1st	2nd	3rd	4th
Characteristic value		3.36	1.91	1.08	0.99
Accumulative contribution rate		0.42	0.66	0.79	0.92
Coefficients of principal component	TP	0.31	0.43	0.35	0.24
	pH	0.08	−0.30	−0.08	0.52
	TN	0.37	−0.35	0.24	0.18
	SS	−0.07	−0.13	0.59	0.34
	CON	−0.23	0.27	−0.58	0.45
	Chl-a	0.42	0.11	0.11	0.50
	SD	0.20	0.00	0.09	−0.18
	Tw	0.08	0.52	0.03	−0.18

Table 3 Results of the principal components analysis at point No.6

Correlation coefficients

	TP	pH	TN	SS	CON	Chl-a	SD	*Tw*
TP	1.0							
pH	−0.49	1.0						
TN	−0.40	0.06	1.0					
SS	0.07	−0.46	−0.10	1.0				
CON	−0.15	0.38	0.43	−0.59	1.0			
Chl-a	−0.17	0.24	0.23	0.23	0.26	1.0		
SD	−0.24	0.47	−0.03	−0.80	0.57	−0.09	1.0	
Tw	−0.49	0.79	−0.09	−0.38	0.50	0.29	0.54	1.0

Contribution of Various principal components

Principal component		1st	2nd	3rd	4th
Characteristic value		3.44	1.61	1.21	0.90
Accumulative contribution rate		0.43	0.63	0.78	0.90
Coefficients of principal component	TP	0.28	−0.44	−0.13	0.39
	pH	−0.40	0.10	0.44	0.43
	TN	0.12	−0.34	0.67	−0.25
	SS	0.65	−0.08	−0.22	0.01
	CON	−0.38	−0.64	−0.21	0.17
	Chl-a	0.02	0.26	0.08	−0.37
	SD	0.22	0.39	0.14	0.65
	Tw	0.36	−0.21	0.47	0.03

different principal components, the most influential factors are conductivity, SD, TP and TN for the first principal component. It is evident that conductivity, transparency, TP and TN together play an important role in water quality of the sampling point No. 0. For the second principal component, only suspension (SS) is obviously important factor. The water temperature (Tw) and TP play a main role for the third one. Since the principal components are independent from each other, they reflect three different mechanisms of pollution. The first one, which has contribution of 42%, represents the factor influencing water quality of the Liangxi River, that is, pollutant's discharge of cities. The second can be considered as the influences of water disturbance by wave and ships in the channel along the river, that is, the increase of SS by water disturbance. The third is connected with the weather and season changes. It is noted that TP is sensitive to seasonal changes.

Similarly, by analysing Table 2, it can be shown that TP – Chl-a, pH – Chl-a, TN – Chl – a, Tw – Chl – a and Tw – pH all have positive correlation while SS – SD and SD – Chl-a are negative correlated for the point No. 4 which lies in the center of Meiliang Bay. This indicates that the variation of TN, TP and water temperature will evidently affect the growth of algae for the point, and on the other hand, both suspensions and algae content play an important role in transparency. According to the composition of the principal components at point No. 4, SS and Chl-a have largest coefficients in the first principal component, while the coefficients for TN and TP have the second position. It indicates that solid suspensions and algae in the first place and TN and TP in the second all have important effect on water quality at this point. Since the location of point No. 4 is far away from the Liangxi River mouth and Lujiangkou mouth, the dilution of pollutants with lake water in certain degree reduces the sensitivity of water quality of this point to TN and TP, on the other hand, the extended water and wind disturbance increase the solid suspensions. Thus, relatively the concentration of solid suspension and the number of algae appear to have larger influences. As SS has a large negative coefficient at this point, it can be interpreted by negative correlation of SS – SD, that is, the increase of solid suspension leads to higher water turbidity and lowers the transparency and water quality. The situation of the second principal component for point No. 4 is similar to the third principal component of point No. 0. Both water temperature and TP have larger coefficients. This can be considered as the influences of weather and seasonal changes. The results of principal component analysis for point No. 6 is shown in Table 3, it can be seen that Tw – pH, Tw – SD and COD – SD have higher positive correlation, while SS – SD and SS – CON have higher negative correlation. It is noted that the higher correlation is related to nonbiological factors SS and Tw, expressing the feature of extended water of Meiliang Bay. Viewing the coefficient's comparison of various factors of the first principal component, it also indicates that only SS has larger coefficient, showing that suspension is the main influential factor of water quality for the point, because point No. 6 lies in outside of Meiliang Bay where wind is more strong and makes suspension being more. For the second principal component at the point, the conductivity and TP have larger coefficients, the reason for this is not known yet. The coefficients of water temperature and TN for the third principal component are larger, it also can be considered as influences of seasonal change.

III. CONCLUSION

Based on the data of 1991 – 1992, the law of dynamic variation of water quality and influential factors for Meiliang Bay water in northern Taihu Lake have been analysed in this paper. The results are preliminary since the data is not long. However, the phenomena revealed are generally reasonable:

(1) Water quality factors vary with both space and time and the main influential factors are different in different waters.

(2) Phosphorus is an important factor of water quality for this water area. Its mean value for long time (for instant, one year) indicates that there exists a good correlation between Chl-a and TP, except for the Liangxi River mouth where TP is very high, while Chl-a does not increase obviously.

(3) In extended water area, suspensions is not a neglectable factor for water quality. For Taihu Lake, the transparency is determined together by both SS and Chl-a content.

(4) It is shown by correlation and principal component analysis that TP, TN, suspensions (or transparency), water temperature and Chl-a are all the most important and influential factors of water quality.

REFERENCES

[1] Jin Xiangcan *et al*. Eutrophication of Lakes in China. Beijing: Chinese Environmental Science Press, 1990. 185 – 194. (in Chinese)

[2] Cai Houjian *et al*. Relations between primary production of phytoplankton and relative factors at mouth of Meiliang Bay in Taihu Lake. J. of Lake Sciences, 1994, 6 (4): 340 – 347. (in Chinese)

[3] Hu Guoding *et al*. Multivariate Analysis Method of Data. Tianjin: Nankai University Press, 1990. 149 – 181. (in Chinese)