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Assessment of the spatial–temporal eutrophic character in the Lake Dianchi

XING Kexia[1], *GUO Huaicheng*[1], *SUN Yanfeng*[1], *HUANG Yongtai*[2]
(1. College of Environmental Sciences, Peking University, Beijing 100871, China;
2. Yunnan Institute of Environmental Science, Kunming 650034, China)

Abstract: Water-quality deterioration and eutrophication of the Lake Dianchi have acquired more and more attention in the last few decades. In this paper, the spatial and temporal eutrophication status of the Lake Dianchi was assessed. The comprehensive trophic state index was chosen to assess the trophic status of the Lake Dianchi in the past 13 years. The result reveals that the trophic condition of Caohai is more serious than that of Waihai. Most of time Caohai was in extremely hypereutrophic state from 1988 to 2000. The trophic condition of Waihai had a worsening tendency from 1988 to 2000. Waihai was in eutrophic state before 1995, but it got in a hypereutrophic state after 1995. It was pointed out that TN and TP were the two biggest contributors of $CTSI_M$ in both Caohai and Waihai.

Key words: Lake Dianchi; Caohai; Waihai; eutrophication assessement; TSI
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1 Introduction

Eutrophication is the most widespread water quality problem in China and many other countries. Symptoms such as high levels of chlorophyll a, excessive seaweed blooms, occurrence of anoxia and hypoxia have occurred in many areas. Water-quality deterioration and eutrophication have acquired more and more attention from the public and government. Many studies have been carried out on lakes' trophic status assessment in China (Wang *et al*., 1994; Tuo, 2002; Zhang *et al*., 2002). In the analysis of causes, it was found that rapid industrialization, urbanization and population growth in the last few decades have caused serious deterioration of water quality (Ren *et al*., 2003). The water quality change is a result of economic development and sewage treatment.

The Lake Dianchi is currently one of the most eutrophied lakes in China, with high turbidity and very rich nutrient. In the 1950s the lake water was very clear. Spreading industrialization, land abuse, population growth, and land reclamation at the shore line resulted in turbid lake waters and blue-green algae bloom in particular areas. During the 1960s and 1970s the lake water became turbid. More recently, due to expansion of Kunming City, the uncontrolled discharge of domestic and industrial effluent has seriously contaminated water in Caohai and Waihai. The water quality of the whole lake belonged to Class II in the 1960s. It increased three classifications in the next 40 years (Kunming Environmental Science Institute, 1997). Now the water quality of Caohai is inferior to Class V, and that of Waihai is in Class V. With the increasingly deteriorating water quality, the trophic condition of Lake Dianchi became more and more serious. The trophic status of Caohai stepped on a severer level every 10 years and that for Waihai was every eight years in the last few decades (Tuo, 2002). This paper focuses on the spatial and temporal eutrophication assessments of Lake Dianchi. The trophic state index is selected to assess the trophic status of the lake.

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Foundation: Key Task Planning of Yunnan Planning Commission
Author: Xing Kexia (1977-), Ph.D. candidate, specialized in environmental planning and management.
E-mail: xingkexia@pku.org.cn

2 Study area

The Lake Dianchi is located in the middle of the Yunnan-Guizhou Plateau, Southwest China. It has a total surface area of 298 km^2, a mean depth of 5.3 m, and the largest storage capacity 15.6×10^8 m^3. The water body of the Lake Dianchi is divided into two parts by a manmade dike, which named Caohai and Waihai. Caohai lies in the north of the Lake Dianchi. Waihai is the main water body of the Lake Dianchi, which accounts for 96.7% of the whole area (Figure 1).

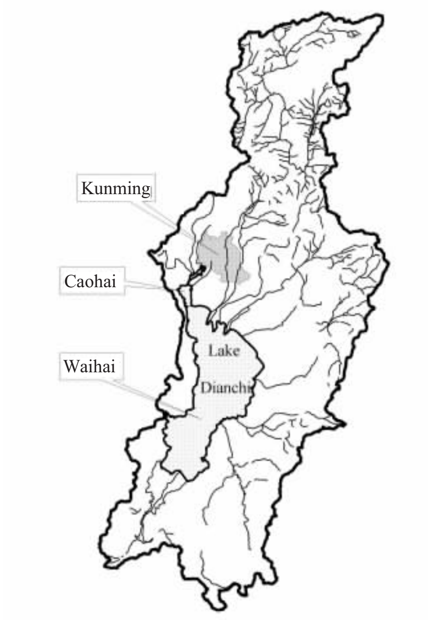

Figure 1 Location of Lake Dianchi

The Lake Dianchi is the main water source for production and living of Kunming City. Water-quality deterioration associated with socio-economic development in the Lake Dianchi has acquired more and more attention from the public and the government since the 1970s. It is threatening people's health and socio-economic development in the basin. The water quality has not been improved although much work has been put into practice. The eutrophication problem has not been solved. It has become a main problem restricting economic development of Kunming City.

3 Data and methods

3.1 Data and sampling points

The spatial-temporal eutrophication characteristic analysis will be helpful to watershed management. The data collected include COD, TP, TN, SD and CHLA concentrations in 1999 at 10 sampling points and the average concentration of COD, TP, TN, SD and CHLA in Caohi and Waihai from 1988 to 2000.

The sampling points in 1999 are showed in Figure 2. There were 10 water-quality sampling points in 1999. Of which, two were in Caohai (points 1 and 2), and the other eight were in Waihai. The names for each sampling point from 1 to 10 are: Duanqiao, the center of Caohai, Luojiaying, middle of Huiwan, west of Guanyinshan, middle of Guanyinshan, east of Guanyinshan, Baiyukou, west of Haikou and south of Dianchi. The sampling depth for each point is 0.5 meter below water suface and the monitoring frequency is once a month.

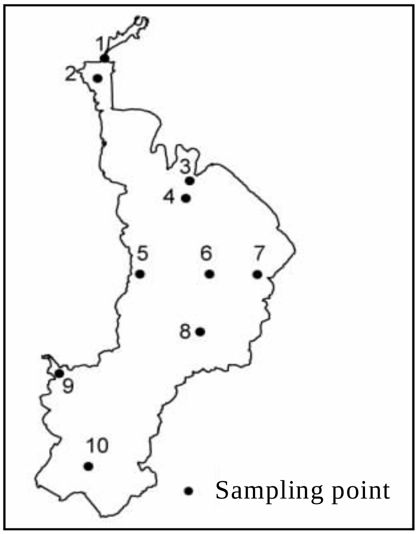

Figure 2 Distribution of sampling points of Lake Dianchi in 1999

3.2 Methods

There are many mathematical methods for lake eutrophication assessment, such as statistical regression analysis (Arhonditsis *et al.*, 2003), cluster analysis (Reisenhofer *et al.*, 1995), fuzzy analysis (Cao, 1991), principal component analysis (Guo and Li, 2002), trophic state index (Carlson, 1977; Xu *et al.*, 2001; Cai, 1997) and artificial neural networks (Li, 1995; Lu and Zhu, 1999), etc. Among the above six major methods, the trophic state index proposed by Carlson is probably the most acceptable method for lake eutrophication evaluation, since it provides a continuous numerical class of lake trophic state and a rigorous foundation for quantitative studies of eutrophication mechanism (Xu *et al*., 2001).

Evaluation of the trophic state of a lake is in fact a multivariate comprehensive decision making process quantifying the qualitative problem. In this study, the trophic state index (TSI) is chosen to assess the trophic state of the Lake Dianchi. The trophic state index is a general method for evaluating lake's trophic state. It was proposed by Carlson in 1977 (Carlson, 1977). In 1981, Aizaki *et al*. proposed the modified Carson's TSI as follows (Aizaki *et al*., 1981):

$$TSI_M(SD) = 10\times(2.46 + (3.69 - 1.53\times\ln(SD))/\ln2.5) \quad (1)$$

$$TSI_M(CHLA)\ 10\times(2.46 + \ln(CHLA)/\ln2.5) \quad (2)$$

$$TSI_M(TP) = 10\times(2.46 + (6.7 + 1.15\times\ln(TP))/\ln2.5) \quad (3)$$

$$TSI_M(TN) = 10\times(2.46 + (3.93 + 1.35\times\ln(TN))/\ln2.5) \quad (4)$$

$$TSI_M(COD) = 10\times(2.46 + (1.50 + 1.36\times\ln(COD))/\ln2.5) \quad (5)$$

where:

SD: Secchidisk transparency (m);

CHLA: Surface algal chlorophyll a (mg/m^3);

TP: Total phosphorus (mg/l);

TN: Total nitrogen (mg/l);

COD: Chemical oxygen demand (mg/l).

Based on equations (1) to (5), each TSI_M for CHLA, SD, TP, TN and COD is calculated (see Table 1). The 0-100 scale was divided into eight ranges, each range representing a particular trophic state (Table 1).

Table 1 The evaluation standards of the trophic state index (TSI_M) for Lake Dianchi

Eutrophication level	TSI_M	CHLA (mg/ m^3)	SD (m)	TP (mg/l)	TN (mg/l)	COD (mg/l)
Extremely oligotrohpic (0-10)	0	0.10	48.0	0.0004	0.010	0.06
	10	0.26	27.0	0.001	0.020	0.12
Oligotrophic (10-30)	20	0.60	15.0	0.002	0.030	0.24
	30	1.60	8.0	0.005	0.050	0.48
Lower-mesotrophic (30-40)	40	4.10	4.4	0.010	0.16	0.96
Mesotrophic (40-50)	50	10.0	2.4	0.023	0.31	1.80
Upper-mesotophic (50-60)	60	26.0	1.3	0.050	0.65	3.60
Eutrophic (60-70)	70	64.0	0.73	0.110	1.20	7.10
Hypereutrophic (70-80)	80	160.0	0.40	0.250	2.30	14.0
Extremely hypereutrophic	90	400.0	0.22	0.550	4.60	27.0
(80-100)	100	1000.0	0.12	1.200	9.10	54.0

In Carlson's TSI, the relative importance of five factors could be considered as CHLA > SD > TP > TN > COD. According to the relative importance of the trophic state, the weight assignment to the five factors can be calculated by using Saaty's analytic hierarchy process (AHP). The judgment matrix was then presented as:

$$\begin{vmatrix} 1 & 2 & 3 & 7 & 8 \\ 1/2 & 1 & 2 & 3 & 5 \\ 1/3 & 1/2 & 1 & 2 & 3 \\ 1/7 & 1/3 & 1/2 & 1 & 2 \\ 1/8 & 1/5 & 1/3 & 1/2 & 1 \end{vmatrix}$$

The weight vector is calculated as ω = (0.470, 0253, 0.147, 0.081, 0.049), in which, λ_{max} = 5.029, CI = 0.007, PI = 1.12, CR = 0.006. It indicates a satisfactory consistency. The results showed that the above attribution could represent well the relative importance of five parameters.

Then a comprehensive assessment model was built after the weight attributions of the five TSI_M indices were calculated by using the method of analytic hierarchy process (Cai *et al.*, 2002). The model is listed as follows:

$$TSI_M = W(CHLA) \times TSI_M(CHLA) + W(SD)\times TSI_M(SD) + W(TP) \times TSI_M(TP) + W(TN)\times TSI_M(TN) + W(COD)\times TSI_M(COD) \quad (6)$$

where $W(X)$ is the weights for the above five parameters with value in percentage as 47.0, 25.3, 14.7, 8.1 and 4.9 respectively.

The sum of the five weighted TSI_M values is called a comprehensive TSI_M($CTSI_M$) (Cai *et al.*, 2002). The $CTSI_M$ was classified the same as TSI_M in Table 1.

4 Result

4.1 Spatial eutrophic characteristic assessment of Lake Dianchi

The observed data at 10 sampling points in 1999 are used to assess the spatial distribution of the eutrophication condition in Lake Dianchi. There are 12 observed concentration values for each index at each sampling point. The average of 12 observed values for each index was calculated at the 10 sampling points firstly. Then the TSI_M for each parameter at 10 sampling points was calculated according to equations (1) to (5). The results are illustrated in Figure 3.

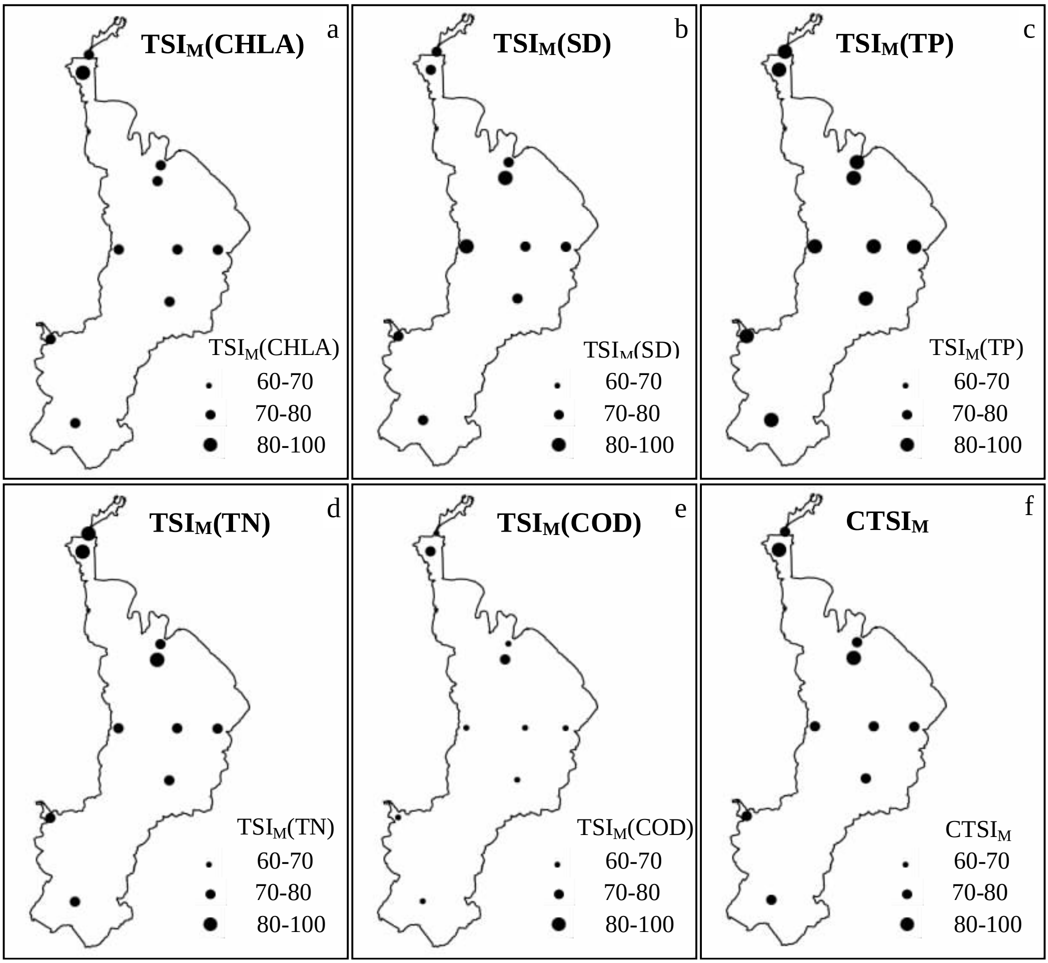

Figure 3 Spatial distribution of the trophic state based on each indicator in 1999
(a) TSI_M(CHLA); (b) TSI_M(SD); (c) TSI_M(TP); (d) TSI_M(TN); (e) TSI_M(COD); (f)$CTSI_M$

Figure 3a shows the spatial distribution of TSI_M(CHLA) in 1999. It can be seen from the figure that only the center of Caohai (point 2) was in extremely hypereutrophic state. The others were in hypereutrophic state. The spatial distribution of TSI_M(SD) is given in Figure 3b. All of the sampling points can be characterized as hypereutrophic state except points 3 and 4. Figure 3c illustrates the spatial distribution of TSI_M(TP). The extremely hypereutrophic field is distributed all of the lake. Figure 3d gives the spatial distribution of TSI_M(TN). There are three sampling points which were in extremely hypereutrophic state. The TSI_M(TN) at sampling points 1 and 2 were greater than that at sampling point 4. The other sampling points in Waihai were in hypereutrophic state. Figure 3e reveals the spatial distribution of TSI_M(COD). Only two of them (points 2 and 4) were in hypereutrophic state. The other eight sampling points were in eutrophic state. The comprehensive assessment of the whole lake is shown in Figure 3f. All of the sampling points can be characterized as hypereutrophic state except points 2 and 4, which were in extremely hypereutrophic state.

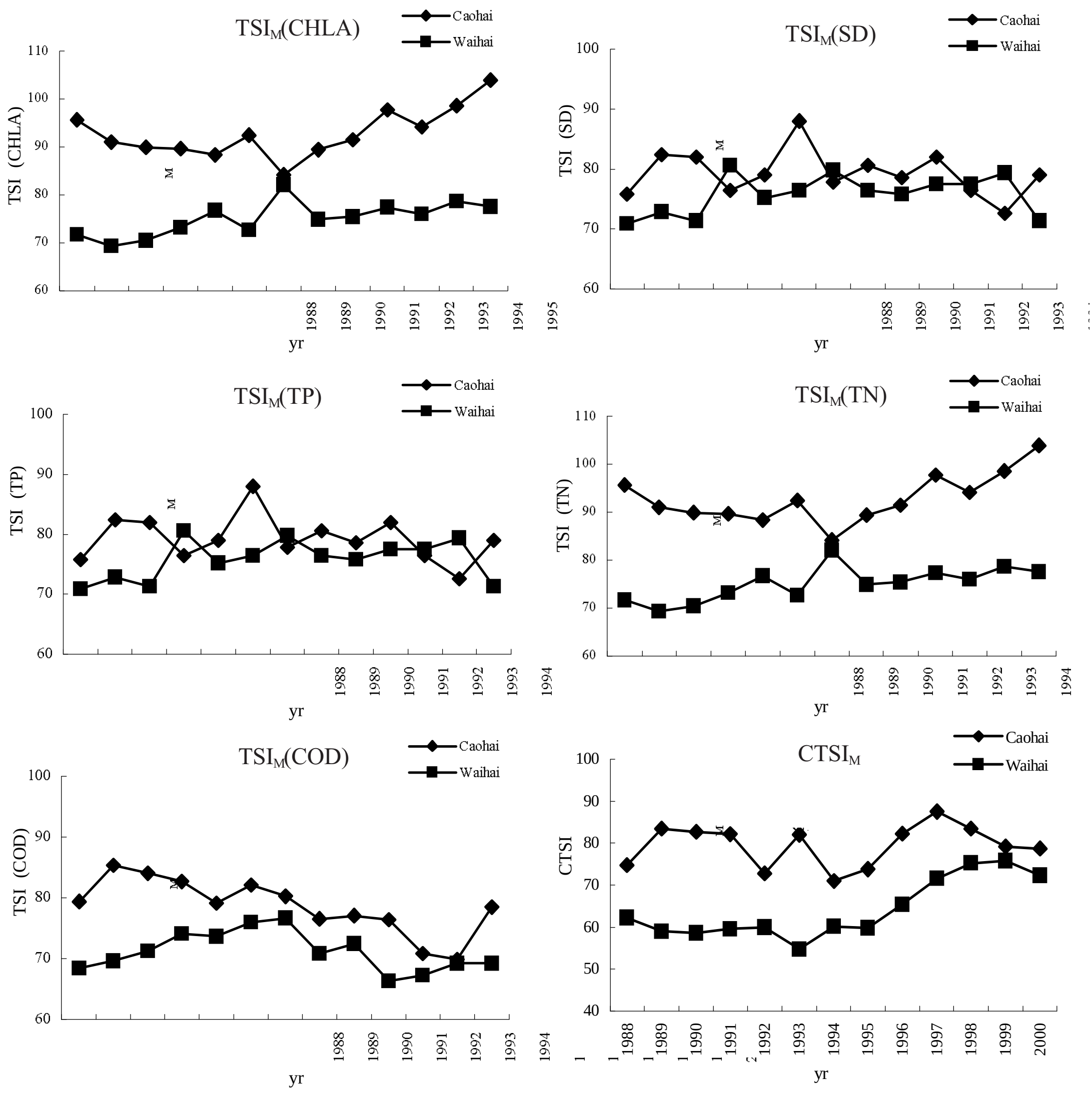

Figure 4 The temporal trophic state assessment for TSI_M(CHLA), TSI_M(SD), TSI_M(TP), TSI_M(TN), TSI_M(COD) and $CTSI_M$

4.2 Temporal eutrophic characteristic assessment of Lake Dianchi

The average concentration for each indicator in Caohai can be calculated by average of points 1 and 2. The average from point 3 to 10 is the average concentration in Waihai. The trophic state index for five indicators and the comprehensive TSI_M from 1988 to 2000 were calculated and illustrated in Figure 4. It can be seen that the trophic state of Waihai became worse in recent 13 years. This is the important reason why the plankton bloomed frequently in recent years. The trophic state curves for Caohai have been undulated since the 1990s (Figure 4). The TSI_M value for each indicator of Caohai in 1998 and 1999 dropped obviously. In the whole, the trophic state of Caohai is higher than that of Waihai. All of TSI_M values for each index of Caohai are much higher than those of Waihai except SD. TSI_M(SD) values for Caohai and Waihai were close to each other from 1988 to 2000.

From the trophic state of single index, the TSI_M(TP) and TSI_M(TN) were the biggest in the past 13 years. They played important roles in the eutrophication of Dianchi Lake. The TSI_M(TP) of Caohai in 2000 exceeded 100 because the average concentration was as high as 11.89 mg/l. The concentrations of TN and TP were remarkable in the latest years. Both TSI_M(TN) and TSI_M (TP) in the whole lake are keeping an upward trend.

5 Conclusions and discussion

The trophic state index was selected to assess the spatial and temporal characteristics of the trophic condition of Lake Dianchi. According to the above analysis, it can be concluded that the trophic state of Caohai is more serious than that of Waihai. Most of time Caohai was extremely hypereutrophic from 1988 to 2000. The trophic conditions of Waihai had a worsening trend from 1988 to 2000. The trophic state of Waihai was in eutrophic state before 1995, but it got in a hypereutrophic state after 1995. From the single indicator TSI_M, the biggest contributors of $CTSI_M$ are TN and TP in both Caohai and Waihai.

The reason for spatial-temporal eutrophic characteristics of Lake Dianchi can be summarized as follows:

(1) There are three main sources of nutrient. The first source is point source. Although four sewage treatment plants have been built and put into operation since 1988 in the basin, all of them are secondary treatment, that is, most of nitrogen and phosphorus can not be removed from wastewater. Another important source of nitrogen and phosphorus is non-point sources. Xing *et al*. pointed out that the TN and TP contribution of non-point sources accounted for more than 40% in 1989 (Xing *et al*., 2004). Plenty of nitrogen and phosphorus went into the lake every year, a large portion of them settled down in the mud, which is the third source of the nutrients resulting in eutrophication of the lake.

(2) Because Caohai is close to Kunming City, a large amount of domestic and industrial wastewater discharges into Caohai every year. About 45% of pollution loads of the whole lake drained to Caohai in 2000 (Li, 2003). But the storage capacity of Caohai only occupies 1.3% of the whole lake. This makes up of the main reason why the trophic state of Caohai is higher than that of Waihai.

(3) The trophic state curves for Caohai undulated intensively. The main reason can be explained as the storage capacity of Caohai is small and it is highly interfered by external factors. The trophic state of Caohai in 1998 and 1999 got a little drop. It can be attributed to a set of projects implemented in Lake Dianchi basin, such as sewage treatment plant built-up and benthic mud dredge-up in Caohai. With the amount increase of fertilizer application in agricultural land and exploitation of phosphorite around Lake Dianchi, the trophic state of Waihai gets a sustainable growth. It has been in a supereutrophic state since 1996.

References

Aizaki M *et al*., 1981. Application of modified Carlson's trophic state index to Japanese lakes and its relationships to other parameters related to trophic state. *Res. Rep. Natl. Inst. Environ. Stud.*, 23: 13-31.

Arhonditsis G, Eleftheriadou M, Karydis M *et al*., 2003. Eutrophication risk assessment in coastal embayments using simple statistical models. *Marine Pollution Bulletin*, 46: 1174-1178.

Carlson R E, 1977. A trophic state index for lakes. *Limnol. Oceanogr.*, 22: 361-369.

Cai Qinghua, 1997. On the comprehensive evaluation methods for lake eutrophication. *Journal of Lake Sciences*, 9 (1): 89-94. (in Chinese)

Cai Qinghua, Liu Jiangkang, King Lorenz, 2002. A comprehensive model for assessing lake eutrophication. *Chinese Journal of Applied Ecology*, 13(12): 1674-1678.

Ding Yun, 2002. The study on the water pollution and agricultural nonpoint source of Dianchi valley. Beijing: Peking University master dissertation. (in Chinese)

Guo Huaicheng, Sun Yanfeng, 2002. Characteristic analysis and control strategies for the eutrophicated problem of the Lake Dianchi. *Progress in Geography*, 21(5): 500-506. (in Chinese)

Guo Tianyin, Li Hailiang, 2002. Application of principal component analysis in the comprehensive evaluation on high eutrophication of lakes. *Journal of Shaanxi Institute of Technology*, 18(3): 63-66. (in Chinese)

Kunming Environmental Science Institute. Water pollution prevention "Ninth Five-Year Plan" and 2010 planning for the Lake Dianchi basin, 1997. (in Chinese)

Li Farong, 2003. Trend analysis of water body sight and aquicolous ecosystem in Dianchi Inner Lake. *Yunnan Environmental Science*, 22: 97-100. (in Chinese)

Li Zuoyong, 1995. A water quality assessment model for trophic state based on B-P neural network and its verification. *Acta Scientiae Circumstantiae*, 15(2): 186-191. (in Chinese)

Lu Wenxi, Zhu Tingcheng, 1999. Artificial neural network evaluation of nutrient states of South Lake water in Changchun. *Scientia Grographica Sinica*, 19(5): 462-465. (in Chinese)

Ma Dengjun, Zhang Fenge, Gao Yunxia *et al*., 2002. The water quality eutrophication evaluation of Guanting Reservoir. *Environmental Monitoring in China*, 18(1): 41-44. (in Chinese)

Reisenhofer Edoardo, Picciotto Alessio, Li Dongfang, 1995. A factor analysis approach to the study of the eutrophication of a shallow, temperate lake (San Daniele, North Eastern Italy). *Analytic Chimica Acta*, 306: 99-106.

Ren Wenwei, Zhong Yang, John Meligrana *et al*., 2003. Urbanization, land use, and water quality in Shanghai 1947-1996. *Environment International*, 29: 649-659.

Tuo Yuanmeng, 2002. Eutrophication of Dianchi and its trend and treatment. *Yunnan Environmental Science*, 21 (1): 35-38. (in Chinese)

Wang Jun, Jiang Jianxiang, Lv Yaokun *et al*., 1994. Evaluation of the lake and the reservoir nourishment in Jilin Province. *Journal of Northeast Normal University*, 2: 90-93. (in Chinese)

Xing Kexia, Guo Huaicheng, Sun Yanfeng *et al*., 2004. Simulation of non-point source pollution in Lake Dianchi basin based on HSPF model. *China Environmental Science*, 24(2): 229-232. (in Chinese)

Xu Fuliu, Tao Shu, Dawson R W *et al*., 2001. A GIS-based method of lake eutrophication assessment. *Ecological Modelling*, 144: 231-244.