Impact of aquaculture on eutrophication in Changshou Reservoir *

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Abstract As a result of intensifying human activities around the Changshou Reservoir, water environmental quality has declined over the years. Water quality had been monitored from 1999 to 2002. The result indicated that the concentrations of total nitrogen (TN) and total phosphorus (TP) are high. The concentrations of phosphorus range from 0.037 mg/L to 0.444 mg/L, exceeding the critical value (0.02 mg/L) for eutrophication. The concentrations of total nitrogen and chlorophyll *a* range from 0.70 mg/L to 4.18 mg/L and from 1.10 mg/m^3 to 61.2 mg/m^3, respectively. The eutrophication status of the water body was assessed using the method of integrated nutrition state index, which revealed that all sampling sites were eutrophicated from the year of 2001. About 69.6% of the annual total nitrogen input and 26% of the annual total phosphorus input originated from the upstreams. The contributions of nitrogen and phosphorus from precipitation to the water body are very small (0.9% and 0.3%, respectively) owing to their low contents (1.21 mg/L and 0.029 mg/L, respectively). Runoff is the secondarily important input source, which accounts for 19.0% of the total N input and 47.0% of the total P input, respectively. Attention should be paid to the aquaculture inputs, whose contributions account for 10.5% of the total N and 26.6% of the total phosphorus to the water body, respectively. Nutrient loads are estimated to be 118 gNm^{-2} · a^{-1} and 8 gPm^{-2} · a^{-1}. About 69.4% of nitrogen and 79.7% of phosphorus input into the reservoir were retained in 2002.

Kay words aquaculture; eutrophication; Changshou Reservoir; nutrition status

1 Introduction

Eutrophication can be understood as a phenomenon of the enrichment of nutrients in a water body. The most important nutrients that cause eutrophication are phosphates, nitrates and ammonia (Cai Qinghua, 1993; Horne and Goldman, 1994). The most prominent features of eutrophic waters are the high contents of nutrients and the abundance of planktons or attached algae. Eutrophication is a common phenomenon for water bodies in China (Jin Xiaocan et al., 1995). The sources of nitrogen and phosphorus could be classified as point and non-point pollution. The main point-pollution sources are industrial and domestic wastes. Runoff and precipitation are the main non-point sources. In the developed countries, point-pollution sources are well controlled. However, in the developing countries, for example in China, the point-pollution sources are still threatening water bodies because of high treatment expenses. Consequently, eutrophication will be a factor affecting water quality in the long-term sense in these countries. China's agriculture is conducted at a high fertilizer application rate in order to support its large population. Large amounts of fertilizer enter into the runoff, bringing about negative effect on water quality (Wang Xiaoyan et al., 2002). In China almost all lakes and reservoirs are surrounded by aquicultural crops, but the problem of aquicultural pollution that affects water quality is usually ignored.

Investigation on the variation of water quality in the Changshou Reservoir is of great significance. Firstly, the aquaculture mode of the Changshou Reservoir has been widely adopted in the provinces of Guizhou, Sichuan, Yunnan and so on. Comparing with usual aquaculture modes, not only feedstuff, but also nitrogenous-phosphate fertilizers and animal dejecta are input into water body to improve the output of fish. This kind of mode would affect water quality more seriously than the usual one. Secondly, recently an aquaculture project of the Three Gorges Reservoir is carried out. Developing aquaculture is regarded as one of the methods

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for the improvement of economy in the Three Gorges region. At the beginning of the 1990's, the Changshou Reservoir was investigated to understand contamination diffusivity due to its similar hydraulic conditions to those of the Three Gorges Reservoir (Huang Shida et al., 1994). Thus, study on the change of water quality of the Changshou Reservoir influenced by agricultural activities is of great practical significance for the management of agriculture in the Three Gorges Reservoir area.

The aims of this study are: 1) to investigate nutrient change and conduct eutrophication assessment in the reservoir; and 2) to estimate the loads and budgets of nitrogen and phosphors and the contributions of the given sources to the loading with an emphasis on the aquacultural sources.

2 Material and methods

2.1 Study area

The Changshou Reservoir is a huge man-made reservoir located in Changshou County, Chongqing, China. It was built in the 1950's. The reservoir has been used for water storage, electric power generation and flood control. Since the late 1990's, aquiculture has developed rapidly. The reservoir (29°57'N, 107°20'E) has a water surface area of 67 km^2, a water volume of 1027 million m^3, and a mean depth of 10 m. The maximal depth is approximately 50 m. The Longxi River and precipitation are its main water sources. The Longxi River is about 218 km long and about 3248 km^2 in drainage area. The Longxi River flows through several counties, where industrial and domestic wastes are discharged into the river, making the water quality worsen. In recent years, the water quality has declined rapidly with the development of tourism and aquaculture.

2.2 Sampling

Sample sites were set at the entrance of the reservoir (site No. 1), inside the bunds (site Nos. 2, 3, 4), and near the dam (site No. 5). Sampling was carried out two times in May and October in the years from 1999 to 2001; when water blooming broke out in the Changshou Reservoir in 2002, new sampling sites (1#, 2#, 3#, 4#) were set. Water samples were collected from the mid stream at 0.5 m below the water surface. Five liters of water sample collected from each site were brought back to the laboratory for the analysis of water quality parameters such as total nitrogen, total phosphorous and chlorophyll *a*. During the transport the samples were kept in an icebox and subsequently transferred to the refrigerator. All the samples were analyzed within 24 hours.

Fig. 1. Monitoring sites in the Changshou Reservoir. The numbers marked by # represent the sampling sites in the year of 2002; those without # indicate the sampling sites in the years of 1999 - 2001.

2.3 Analytical methods

Total nitrogen (TN) was determined by UV spectrophotometry after digestion by alkaline $K_2S_2O_8$. Total phosphorus (TP) was analyzed using the molybdate method after digestion with $K_2S_2O_8$ (Wei Fusheng, 1989). Light transmission was determined on-site using a 0.3-m Secchi disc. One liter of sample was filtered through a piece of filter paper (Whatman GF/C: 0.45 mm in pore size, 5.0 cm in diameter) using vacuum filtration assembly. Filter paper (with residue) was then crushed in a pestle and mortar and transferred to the centrifuge tubes which were repeatedly washed with acetone. Centrifugation was done for 10 min at 5000 rpm (>500G). Optical density (OD) of the supernatant was measured at 665 and 750 nm using a 1-cm path-length cell. The extract was then acidified with 2 drops of 1 N HCl and gently agitated. The OD was measured at 1 - 2 min intervals after acidification at 665 and 750 nm using the same cell. 90% aqueous acetone solution was used as blank. Chlorophyll *a* in mg/m^3 was estimated by $\{27.3\ (OD665_b\text{-}OD665_a)\ A\}/B$, where a and b are the total volumes in liters of the acetone extractant and original sample, respectively, and $OD665_b$ and $OD665_a$ are the turbidity-corrected OD values before and after acidification using a 1-cm cell, respectively. The turbidity-corrected OD values were obtained by subtracting the OD values at 750 nm from the OD values at 665 nm, respectively (Liou Hongliang, 1990; Vinod et al., 2002).

2.4 Eutrophication assessment methods

The integrated trophic state index method was adopted to assess the trophic state of the reservoir, which has been established based on the investigation results for 26 lakes and reservoirs in China. The computational forms of the trophic state index can be defined as:

$$TLI(\sum) = \sum_{j=1}^{m} Wj \cdot TLI(j)$$

where $TLI(\sum)$ is the integrated trophic state index, W_j the corresponding weight coefficient of factor j and $TLI(j)$ is the trophic state index of factor j. The computational forms of weight coefficient are presented as follows:

$$W_j = \frac{r_{ij}^2}{\sum_{j=1}^{m} r_{ij}^2}$$

where r_{ij} is the correlation coefficient of benchmark parameter (chlorophyll *a*) and j, m is the number of parameters.

Table 1. Correlation coefficients between chlorophyll *a* and TP, TN, SD and COD

Parameter	Chl *a*	TP	TP	SD	COD
r_{ij}	1	0.84	0.82	-0.83	0.83
r_{ij}^2	1	0.7056	0.6724	0.6889	0.6889
W_j	0.2663	0.2237	0.2183	0.2210	0.2210

The r_{ij} results come from the investigation of 26 lakes in China (Jin Xiaocan et al., 1995).

The calculation formulae of trophic state indices of chlorophyll *a*, TP, TN, SD and COD are presented as follows:

$$TLI(\text{chl } a) = 10[2.5 + 1.086 \ \ln \text{chl } a \ (\text{mg/m}^3)]$$
$$TLI(\text{TP}) = 10[9.436 + 1.624 \ \ln \text{TP} \ (\text{mg/L})]$$
$$TLI(\text{TN}) = 10[5.453 + 1.694 \ \ln \text{TN} \ (\text{mg/L})]$$
$$TLI(\text{SD}) = 10[5.118 - 1.94 \ \ln \text{SD} \ (\text{m})]$$
$$TLI(\text{COD}) = 10[0.109 + 2.661 \ \ln \text{COD} \ (\text{mg/L})]$$

A series of successive digital classification from 0 to 100 is used to define the trophic state. $TLI(\sum) < 30$ (oligotropher), $30 \leq TLI(\sum) \leq 50$ (mesotropher), $TLI(\sum) > 50$ (eutropher), $50 < TLI(\sum) \leq 60$ (light eutropher), $60 < TLI(\sum) \leq 70$ (middle eutropher), $TLI(\sum) > 70$ (hyper eutropher). At the same trophic state, the higher the numerical index is, the more serious the eutrophication level will be.

3 Results and discussion

The data (Table 2) indicated that the nutrient concentrations were high in the years from 1999 to 2001. Maximal TN concentrations of nutrients generally occurred at the entrance of the reservoir (site No. 1) except those in Oct. 2000, suggesting that the water source of the reservoir from the upstream was heavily polluted by industrial and domestic wastes. The distribution of TP concentrations varied in accordance with the aquacultural extent. The concentrations of TP, ranging from 0.037 mg/L to 0.444 mg/L, exceeded the critical value (0.02 mg/L) for eutrophication (OECD, 1982). The concentrations of TN ranged from 0.70 mg/L to 4.18 mg/L. Transparency was low, varied from 0.5 m to 1.55 m, which was caused not only by phytoplankton growth, but also by soil erosion suspension. The COD ranged from 2.41 mg/L to 7.19 mg/L.

Before the year of 2001, the concentrations of chlorophyll *a* were low and the water quality was in the state from the oligotropher to the mesotropher according to OECD standard (1982). However, water quality has declined significantly since 2001. The water quality at all sampling sites in the reservoir was in the state of eutropher. From 1999 to 2001, chlorophyll *a* changed from 1.10 mg/m^3 to 61.2 mg/m^3, it almost increased by fifty times. However, the concentrations of nitrogen and phosphorus don't follow the same trend as chlorophyll *a*. A part of nutrients in the water body was consumed by algae possibly and hydrophytic plants were captured to breed livestock.

From July to August in 2002, water blooming broke out in the Changshou Reservoir. Three water blooming areas and one sanitary area were selected to analyze the difference in water quality. The results are given in Table 3. The sampling sites are shown in Fig. 1. No water blooming broke out at site No. 1#, but it did at the other sites. The concentrations of TP at site No. 1# are lowest among all sampling sites, but the highest concentrations of TN occurred there. In the Changshou Reservoir area, over-dose nitrogen fertilizer was used in cultivated land and aquacultural production, which led to a ratio of TN/TP of about 100 in the water body. Obviously, the limiting nutrient for algae blooms is phosphorus. The values of COD were low in the years from 1999 to 2002, indicating that carbon wasn't the main factor affecting algae growth in the Changshou Reservoir. The concentrations of saturated dissolved oxygen were estimated to be 7.54 mg/L at 30℃. The DO amounts of all the sampling sites exceeded the normal concentration value and the maximum value exceeded the normal level by 54%. It is indicated the photosynthesis of algae would affect the dissolved oxygen concentrations. Transparency in water blooming area is far below that in normal years. Algal growth reduced transparency in the water body.

Table 2. The variation of TN, TP, Chl *a*, COD and SD in the years from 1999 to 2001

		TN (mg/L)		TP (mg/L)		Chlorophyll *a* (mg/m^3)		COD (mg/L)		SD (m)	
		May	Oct.	May	Oct.	May	Oct.	May	Oct.	May	Oct.
1999	1	1.30	3.11	0.123	0.088	2.28	1.55	7.19	3.10	0.5	1.27
	2	0.76	1.46	0.088	0.221	3.95	1.27	4.62	2.79	0.8	1.35
	3	0.79	1.64	0.042	0.117	6.44	1.10	4.11	2.41	1.2	1.43
	4	1.27	1.69	0.145	0.110	4.27	2.48	5.45	2.77	1.0	1.30
	5	1.12	1.68	0.042	0.061	3.95	1.73	4.01	2.50	1.1	1.30
2000	1	4.12	1.72	0.195	0.064	4.53	3.28	4.21	4.74	1.00	1.50
	2	0.70	2.10	0.100	0.204	4.19	3.56	3.91	4.71	1.20	1.45
	3	1.50	2.34	0.122	0.113	4.72	5.21	4.37	4.97	1.25	1.50
	4	0.91	2.12	0.074	0.045	5.19	3.62	3.45	3.32	1.10	1.55
	5	1.59	2.86	0.330	0.047	4.96	3.09	4.06	3.72	1.00	1.50
2001	1	3.12	4.18	0.073	0.130	37.9	44	5.32	4.99	0.90	0.65
	2	1.61	3.32	0.114	0.375	55.2	55	7.14	7.38	0.95	0.77
	3	1.78	3.10	0.098	0.444	49.4	49	5.51	6.91	0.90	0.65
	4	1.22	1.87	0.094	0.184	37.5	52	5.09	5.59	0.95	0.80
	5	2.04	1.68	0.094	0.067	38.0	34	5.33	4.26	0.95	1.00

Table 3. Water quality parameters during algae bloom period in 2002

Monitoring site No.	COD (mg/L)	Chl *a* (mg/m^3)	SD (m)	TP (mg/L)	TN (mg/L)	DO (mg/L)
1#	4.66	13.03	1.2	0.037	3.58	9.94
2#	4.93	52.34	0.65	0.148	3.20	9.94
3#	5.13	61.20	0.62	0.142	2.89	11.6
4#	5.05	52.30	0.62	0.135	2.6	11.1

The relations between chl *a* and TP and SD were analyzed by the regression analysis methods based on the monitoring data accumulated in the years from 1999 to 2002. The following regression equations are established:

$$\lg[\mathrm{Chl}] = \begin{cases} -0.207\lg[\mathrm{TP}] + 0.644 & \mathrm{Chl}\ a < 3.0\ \mathrm{mg/m^2} & r^2 = 0.0754 \\ 0.133\lg[\mathrm{TP}] + 0.351 & 3.0 \leqslant \mathrm{Chl}\ a < 11.0\ \mathrm{mg/m^2} & r^2 = 0.246 \\ 0.423\lg[\mathrm{TP}] + 0.744 & \mathrm{Chl}\ a \geqslant 11.0\ \mathrm{mg/m^2} & r^2 = 0.503 \end{cases} \quad (1)$$

$$\lg[\mathrm{Chl}\ a] = -3.891\lg[\mathrm{SD}] + 1.044 \qquad r^2 = 0.663 \quad (2)$$

According to the OECD standard (1982), the nutrition states of water bodies can be divided into three types based on the chlorophyll *a* contents. No significant correlation between chlorophyll *a* and TP was found at the oligotropher state (chlorophyll $a < 3.0$ mg/m^3) and at the mesotropher state ($3 <$ chlorophyll $a < 11$ mg/m^3), the values are 0.0754 and 0.2467, respectively. However, at the eutropher state (chlorophyll $a > 11.0$ mg/m^3), significant correlations between chlorophyll *a* and TP ($r^2 = 0.504$) and SD ($r^2 = 0.663$) are recognized, as showed in Figs. 2 and 3.

The eutrophic states have been evaluated with the integrated trophic state index method as seen in Table 4. The water quality at all monitoring sites is in the state of light eutropher to hyper eutropher except at site No. 3, where mesotropher state has been found only one time. Especially in 2001, all the sites were in excess of the medium eutropher. The results demonstrated that the water quality of the Changshou Reservoir has declined obviously. The integrated trophic state indices at all sites vary from 49.17 to 76.93.

When water blooming broken out in 2002, the values of *TLI* were 59.64, 71.26, 71.62 and 70.50, respectively. The water body was in the state from light eutropher to hyper eutropher. Comparing the results of eutrophic indices from 1999 to 2002, a clear tendency of eutrophication could be seen. Although the nutrient concentrations before 2001 were high, no serious eutrophication occurred, perhaps it is related to the limited nutrient forms and other environmental factors.

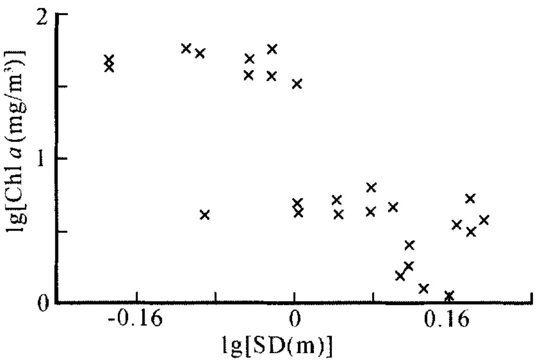

Fig. 2. Relations between transparency (SD) and chlorophyll *a*.

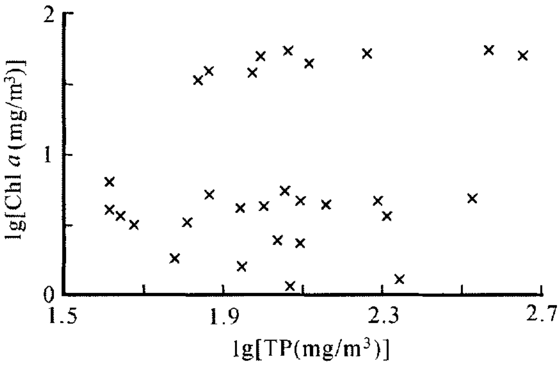

Fig. 3. Relations between phosphorus and chlorophyll *a*.

Table 4. Results of assessment in the monitoring sites

Monitoring site No.	Result of assessment	1999		2000		2001	
		May	Oct.	May	Oct.	May	Oct.
1	Value of *TLI*(Σ)	71.86	53.27	63.34	54.08	66.72	71.34
	Grade	Hyper	Light	Middle	Light	Middle	Hyper
2	Value of *TLI*(Σ)	54.32	55.66	52.19	59.38	68.47	76.56
	Grade	Light	Light	Light	Light	Hyper	Hyper
3	Value of *TLI*(Σ)	51.75	49.17	57.26	58.91	66.68	76.93
	Grade	Light	Mesotropher	Light	Light	Middle	Hyper
4	Value of *TLI*(Σ)	59.26	52.63	53.05	51.63	63.64	69.89
	Grade	Light	Light	Light	Light	Middle	Middle
5	Value of *TLI*(Σ)	51.86	48.83	61.78	53.25	65.85	62.04
	Grade	Light	Mesotropher	Middle	Light	Middle	Middle

Hyper. hyper eutropher; Light. light eutropher; Middle. middle eutropher.

The loads of nitrogen and phosphorus from the upstream were obtained from monthly water sampling and flow rate measurement. Nitrogen and phosphorus in precipitation were determined by monthly analysis of rainwater during the study years. Precipitation data were provided by the Environmental Monitoring Center of Chongqing City. Nitrogen and phosphorus in the surface runoff were known from literature (Huang Shida et al., 1994). According to the statistics data of input into the reservoir, the nutrient input was calculated. The input of nitrogen and phosphorus into the Changshou Reservoir in 2002 is listed in Table 5. The input sources include the upstream, precipitation, land runoff and aquacultural activities.

Among the most important sources of nitrogen and phosphorus input into the reservoir, the upstream input is the largest, accounting for 69.6% of the annual total nitrogen input, and 26% of the annual total phosphorus input. The amounts of nitrogen and phosphorus from precipitation are very small (0.9% and 0.3%, respectively) owing to their low contents in the rainwater (1.21 mg/L N and 0.029 mg/L P, respectively).

Runoff is the less important input source, whose contribution accounts for 19.0% and 47.0% of the annual total phosphorus input, respectively. But the aquacultural input should be noticed. Nitrogenous-phosphate fertilizer and animal dejecta were input into water for fish-raising or for stimulating algal growth. About 10.5% total nitrogen and 26.6% total phosphorus come from aquacultural activities, excluding animal and poultry dejecta (chicken).

The outputs of total nitrogen and total phosphorus were investigated. Nutrient output through water outflow was estimated by measuring outflow volume and the nutrient contents of the said water. Outflow is the most important output factor, by which 2343.6 t N and 100.8 t P were excluded. The amounts of N and P were estimated from their contents in fish and the yields of fish. The average concentrations of N and P in fish were 25.3 g/kg and 6.48 g/kg, respectively, and the fish yields were about 3000 t in 2002, thus the output amounts of nitrogen and phosphorus by fish catch would be 75.9 t and 19.4 t, respectively

Table 5. Input sources of nitrogen and phosphorus

	Upstream	Precipitation	Land runoff	Aquaculture	Sum
Total nitrogen load(t/a)	5511	72.6	1500	831	7914.6
Proportion (%)	69.6	0.9	19.0	10.5	100
Total phosphorus load(t/a)	154	1.74	278.4	157.7	591.84
Proportion(%)	26.0	0.3	47.0	26.6	100

From Table 6, the amounts of total N and total P inputs are 7914.6 t and 591.84 t. The outputs are 2419.5 t and 120.2 t. About 69.4% nitrogen and 79.7% P are retained in the reservoir. Nutrient loading is believed to be the best measure of the nutrition status of a lake (Dillon and Kirchner, 1975). According to Vollenweider (1968), dangerous annual inputs of N and P may amount to 2 $gm^{-2} \cdot a^{-1}$ and 0.2 $gm^{-2} \cdot a^{-1}$, respectively. In the Changshou Reservoir, as high as 118 $gNm^{-2} \cdot a^{-1}$ and 8 $gPm^{-2} \cdot a^{-1}$ were input into the water body, which exceeded the suggested input rate by many times. Similar over-enrichments of nutrients have been recorded for many other Chinese lakes, e. g. 32 $gNm^{-2} \cdot a^{-1}$ and 11 $gPm^{-2} \cdot a^{-1}$ in Caohu Lake, 105 $gNm^{-2} \cdot a^{-1}$ and 13 $gPm^{-2} \cdot a^{-1}$ in Xuanwu Lake, 16 $gNm^{-2} \cdot a^{-1}$ and 8 $gPm^{-2} \cdot a^{-1}$ in Dianchi Lake (Hui Juantang et al., 2000).

Table 6. Balance between nitrogen and phosphorus

Contamination	Input (t)	Output (t)	Sum of retained N and P (t)	Retaining rate (%)
Total nitrogen	7914.6	2419.5	5495.1	69.4
Total phosphorus	591.84	120.2	471.64	79.7

Fish may contribute a lot to the eutrophication of water body by causing an increase in nutrient cycling through excreting N and P (Brand et al., 1990). In Donghu Lake, fish capture is an efficient way for phosphorus removal. It is estimated that about 10% of the external P load can be removed annually (Hui Juantang et al., 2000). However, the results are based on the feeding strategy that any kind of diet is not input into the water body. The growth of fish depends on the amount of nutrients in the water body itself.

Aquaculture would usually lead to an increase in trophic state, especially with respect to aquaculture mode in the Changshou Reservoir. By fish capture, the outputs of nitrogen and phosphorus are 75.9 t and 19.4 t. But, at the same time, the inputs of nitrogen and phosphorus reached 831 t and 157.7 t, respectively because of aquaculture. Clearly, the water body will be polluted by aquaculture. If nutrient sources of animal dejecta are taken into consideration, more serious aquaculture contamination will be expected. This kind of aquaculture should be abandoned to protect water quality.

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