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ORIGINAL ARTICLE

Spatial and temporal water quality characteristics of Poyang Lake Migratory Bird Sanctuary in China

Yue Liang · Huayun Xiao · Xiaozhen Liu · Jian Xiong · Wenhua Li

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Abstract Poyang Lake Migratory Bird Sanctuary includes Bang Lake, Sha Lake, Dahu Lake, and estuaries of the Xiu and Gan Rivers in the Migratory Bird Natural Reserve. Water samples were collected and analyzed to study spatial and temporal water quality variation. Strong seasonal variation of water quality was found. The water quality of Bang Lake was relatively poor compared to Sha and Dahu Lakes in the wet season, but better in the normal season. During the dry season, the water quality of Bang Lake is negatively affected by the activity of migratory birds. According to the correlation analysis of monthly concentrations of each parameter, the concentrations of COD, NH_4^+–N, and NO_3^-–N were highly correlated. The correlation index was 0.829 and significance index was $0.042 < 0.05$. From north to south within Bang Lake, the concentration of TN decreased; however, the concentration of Chl-a increased. From east to west within Bang Lake, concentrations of COD, NH_4^+–N, NO_3^-–N, and Chl-a increased. The Xiu and Gan Rivers influence the water quality of Bang Lake, especially in the northeast area of the lake. The water quality of Bang Lake only reached Chinese water quality standard level IV or V according to a fuzzy comprehensive evaluation. The evaluation factors impacting Bang Lake are TN>TP>NH_4^+–N>COD, in order of decreasing importance. The waters of Poyang Lake Migratory Bird Sanctuary have been polluted; one of the important contributing factors was migratory birds' disturbance and feces.

Y. Liang · H. Xiao (✉) · X. Liu · J. Xiong · W. Li
Key Laboratory of Poyang Lake Environment and Resource Utilization, Ministry of Education, School of Environmental and Chemical Engineering, Nanchang University, Nanchang 330047, Jiangxi, People's Republic of China
e-mail: xiaohuayun@vip.skleg.cn

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1 Introduction

Poyang Lake (Fig. 1) is the largest freshwater lake in China and is situated in a globally important ecological area as designated by the World Wide Fund for Nature (WWF). Poyang Lake is in the Yangtze River Basin, along the southern bank of the middle and lower reaches of the Yangtze River (Deng et al. 2011; Liu and Liu 2012; Lu et al. 2012; Wang et al. 2013a). The water level of Poyang Lake is heavily influenced by flows in the Gan and Xiu Rivers. From fall each year to mid-spring of the next year, Poyang Lake enters a dry season, reducing connectivity to adjacent water bodies. The Gan and Xiu Rivers merge into Poyang Lake at Wucheng, a small town on the western side of the lake. There are numerous small lakes around Wucheng, including Dahu, Sha, and Bang Lakes. Because of its special landscape features, the area is one of the six most important wetlands in the world (Wang et al. 2008). Residents living nearby rely on these lakes for fishing; and the waters near Wucheng have been recognized as an important habitat for migratory birds and protected as the Poyang Lake Migratory Bird Sanctuary.

Humanity's survival depends on ecosystems, like the rich one found at Poyang Lake, but the behavior of expanding biogeochemical cycles greatly affects environmental conditions and people's lives (Vatn 2010; Hadas et al. 2009; Wang et al. 2013b). Water quantity and quality have become serious issues facing many communities and nations around the world, especially following changes in climate that have affected various aspects of regional hydrological cycles (Guo et al. 2008; Kundzewicz et al. 2007; Lehmann et al.

2004). In recent years, the water quality of Poyang Lake has deteriorated (Wu et al. 2011). Specifically, the concentrations of TN and TP have increased significantly because of agricultural irrigation drainage water injection (Wang et al. 2006; Zhen et al. 2011; Deng et al. 2011; Li et al. 2011).

Early research of our group has shown that migratory birds' wintering behavior is one of the causes of the pollution, and the water from the Xiu and Gan Rivers also significantly influence the water quality of Bang Lake.

The spatial and temporal distribution of water quality in the Poyang Lake Migratory Bird Sanctuary was investigated by analyzing COD, TP, TN, ammonia (NH_4^+–N), nitrate nitrogen (NO_3^-–N), chlorophyll a (Chl-a), and other indicators. Effects of the Xiu and Gan Rivers on the water quality of Bang Lake were studied by analyzing the water level fluctuation and comparing water quality in Bang Lake and the Xiu River. The water quality of Bang Lake was evaluated by using the fuzzy comprehensive evaluation method. Compared with other methods, fuzzy comprehensive evaluation can determine the water quality classification with the latest water quality standards, which can well reflect the actual situation of water quality in more objective basis weights. This evaluation method has been widely used in research of various water bodies (Zhou et al. 2013; Liou and Lo 2005; Liou et al. 2003; Wu et al. 2012; Zhang et al. 2012). The water research of Poyang Lake Migratory Bird Sanctuary helps to understand the impact of human activities on the surrounding wetlands, as well as the impact of migratory birds on the environment. This study is relevant for supporting protection of habitat for migratory birds, and also provides basic scientific data regarding the effects of the birds.

2 Materials and methods

2.1 Sample collection

Field samples were collected in June, July, September, October, December, March, April, and May from June 2012 to May 2013. The sampling points were mainly distributed in Dahu, Sha, Bang Lakes; and in estuaries of the Xiu and Gan Rivers. The sampling area is shown in Fig. 1. Sampling depth was 0.3–0.5 m below the water surface. Samples were stored in clean bottles, analyzed immediately after returning to laboratory, and kept under cryopreservation during analysis. Surface sediment samples (0–5 cm thickness) were collected using tube samplers made of polypropylene. Three samples were taken from each location and combined into one sample, sealed in a polyethylene ziplock bag. Sampling points, shown in Fig. 2, varied by month due to restrictions imposed by water depth and traffic conditions. Each sampling point was recorded by GPS.

2.2 Experimental methods

Determination methods of the various physical and chemical indexes were as shown in Table 1 (SEPA 2002). Data were processed by SPSS18.0 and other related software. The overall water quality of Bang Lake, the spatial and temporal distribution of data, correlation between various indicators, and the impacts on water quality of the Xiu and Gan Rivers were studied Table 1.

2.3 Evaluation methods

The fuzzy comprehensive evaluation method was used to analyze the water pollution of Bang Lake. The specific

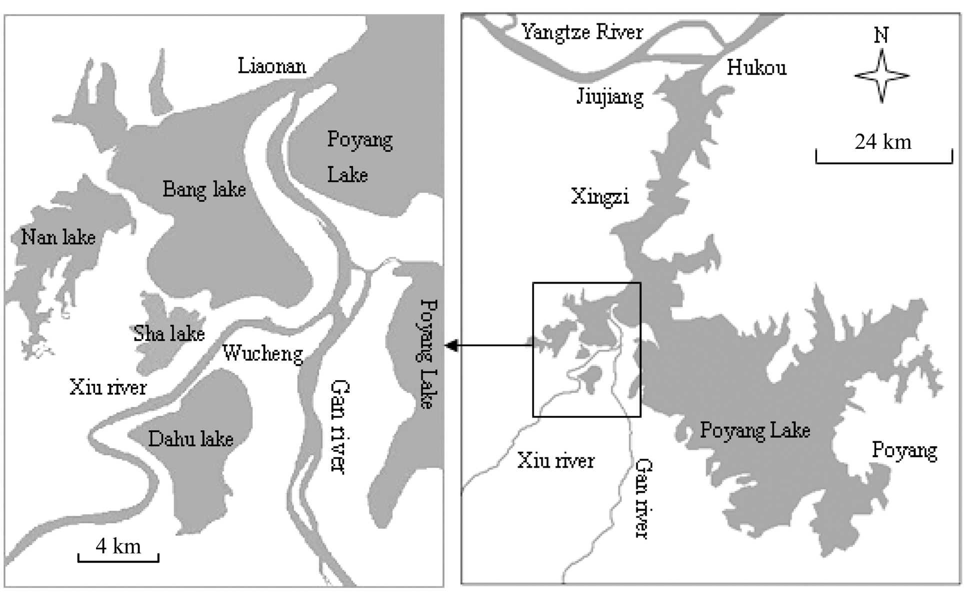

Fig. 1 Distribution of Poyang Lake Migratory Bird Sanctuary waters

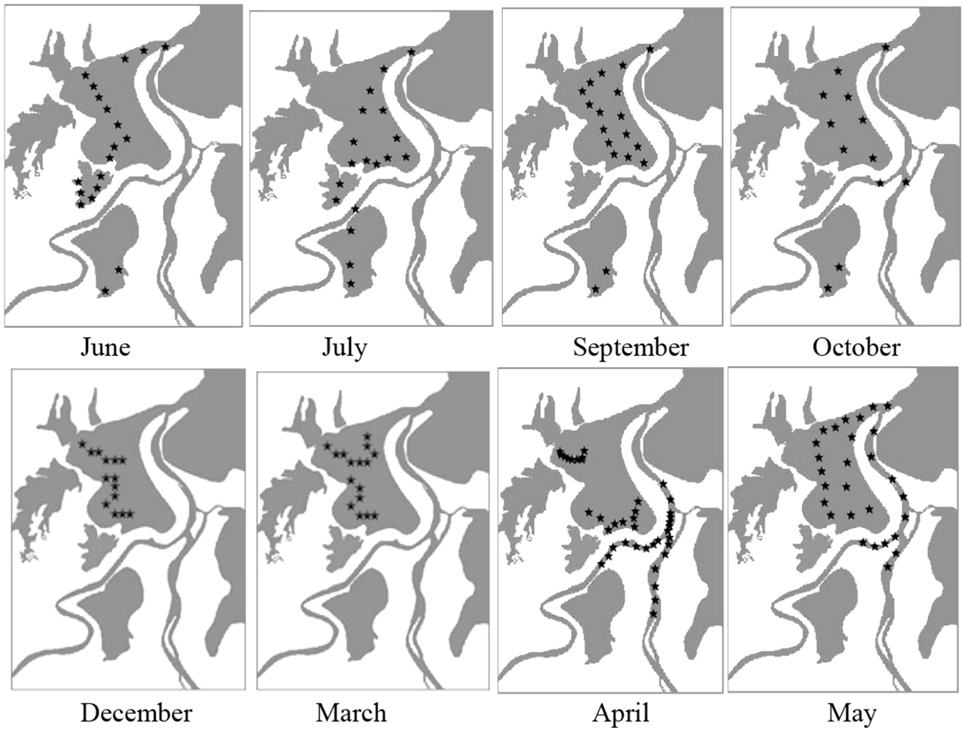

Fig. 2 Monthly sampling sites, June July–September October, December March–April May

Table 1 Detection method of each physicochemical index

NO.	Index	Detection method
1	COD	Potassium dichromate method
2	TN	Persulfate oxidation UV spectrophotometry
3	TP	Molybdenum–antimony resolved by potassium-persulfate and anti-spectrophotometry
4	NO_3^-N	Phenol disulfonic acid spectrophotometry
5	NH_4^+–N	Flocculation Nessler reagent spectrophotometry

water quality grade of the studied water was determined by using the optional evaluation indexes of fuzzy comprehensive evaluation method, combined with "Surface Water Quality Standards." A fuzzy relationship matrix was established, which was helpful to understand the pollution weights of each index. The fuzzy comprehensive evaluation method was divided into following steps (Wu et al. 2012; William et al. 2013):

(A) Establish the fuzzy relationship matrix (Eq. 1). Index u_x indicates degree of affiliation; the larger the value is, the higher the degree of membership:

$$u_x = \begin{cases} 1 & x < a_1 \\ \dfrac{a_2 - x}{a_2 - a_1} & a_1 \le x \le a_2 \\ 0 & x > a_2 \end{cases} \quad (1)$$

where a_1 and a_2 represent the standard concentration values of the two adjacent grades; x represents an index of the measured values.

(B) Use the formula to calculate the value of membership in the fuzzy relationship matrix R:

$$R = \left[R_{ij}\right] = \begin{bmatrix} r_{11} & r_{12} & r_{13} & r_{14} & r_{15} \\ r_{21} & r_{22} & r_{23} & r_{24} & r_{25} \\ & \cdots & & \cdots & \\ r_{n1} & r_{n2} & r_{n3} & r_{n4} & r_{n5} \end{bmatrix} \quad (2)$$

where i ($i = 1,2,3,\ldots,n$) represents the ith item single factor, j ($j =$ I,II,III,IV,V) indicates water quality classification.

(C) Determine the index weights (Eq. 3). Utilize index exceeding method to calculate objective weights of evaluation indexes:

$$w_i = \frac{x_i}{s_{i0}} \quad (3)$$

Since the weights are in the range of [0,1], the weights w_i are normalized:

$$\bar{w}_i = w_i \Big/ \sum_{i=1}^{n} w_i, \ \sum_{i=1}^{n} \bar{w}_i = 1 \quad (4)$$

where w_i denotes the weighting of i and x_i denotes the measured values of the i factor, S_{i0} represents the standard value of Grade III water quality as set in Chinese Surface Water Quality Standards (GB 3838-2002).

(D) Execute comprehensive fuzzy evaluation (Eq. 5).

$$B = \bar{w}_i \bullet R \quad (5)$$

Analysis and evaluation were performed after obtaining results.

3 Results and discussion

3.1 Water quality analysis

Bang Lake feeds Poyang Lake from the west. Flow velocity into the lake is low and the overall water quality of Bang Lake is relatively poor. The average concentration in Bang Lake for each indicator is shown in Table 2 by month along with annual. According to Chinese Surface Water Quality Standards GB3838-2002, the annual average level of NH_4^+–N was in the Grade II, the annual average level of COD and TP were in Grade III, and the annual average level of TN was in Grade V.

Early research (Zhu and Zhang 1997) in the 1980s showed that the annual average values of TP, TN, NH_4^+–N, and NO_3^-–N in Poyang Lake were 0.684, 0.076, 0.136 and 0.192 mg/L, respectively. The annual average concentrations of NH_4^+–N, NO_3^-–N, and soluble inorganic nitrogen (DIN) of Poyang Lake from 2005 to 2006 were 0.42, 0.67, and 1.09 mg/L, respectively (Wang et al. 2008). From the 1990s to the present study, the nutrient concentration of Bang Lake increased significantly, accompanied by an increasing degree of eutrophication.

The waters sampled in this study included Bang Lake, Sha Lake, Dahu Lake, Gan River, and Xiu River. Sampled waters were not consistent due to limitations of water level and traffic conditions. June and July were wet periods, and the water quality of Sha Lake and Dahu Lake was slightly better than that of Bang Lake (Table 3). September and October were normal water level period, water quality of Bang Lake was slightly better than that of Dahu Lake, though not across all parameters. After entering the dry season (from November to March), when tens of thousands of migratory birds winter in the Poyang Lake Migratory Bird Sanctuary, the water quality of Bang Lake became poor. With the departure of migratory birds,

Table 2 Monthly average concentrations in Bang Lake

Month	COD (mg/L)	TP (mg/L)	TN (mg/L)	NH_4^+–N (mg/L)	NO_3^-–N (mg/L)	Chl-a (μg/L)
June	11.920 ± 3.157	0.107 ± 0.015	1.839 ± 0.599	0.235 ± 0.038	0.153 ± 0.039	0.745 ± 0.366
July	21.726 ± 15.284	0.071 ± 0.01	3.874 ± 0.449	0.295 ± 0.05	0.484 ± 0.234	0.951 ± 0.434
September	12.428 ± 8.642	0.121 ± 0.059	2.359 ± 0.518	0.291 ± 0.059	0.086 ± 0.021	1.261 ± 0.440
October	14.698 ± 5.411	0.097 ± 0.025	1.952 ± 1.162	0.324 ± 0.040	0.112 ± 0.107	1.122 ± 0.542
December	21.845 ± 8.600	0.079 ± 0.029	2.116 ± 0.905	0.688 ± 0.368	0.195 ± 0.100	0.641 ± 0.283
March	25.481 ± 6.528	0.119 ± 0.075	1.201 ± 0.635	0.768 ± 0.411	0.279 ± 0.138	2.045 ± 1.243
April	14.208 ± 5.470	0.075 ± 0.031	1.875 ± 1.139	0.516 ± 0.136	0.168 ± 0.141	0.896 ± 0.592
May	6.828 ± 2.885	0.039 ± 0.010	0.515 ± 0.344	0.481 ± 0.189	0.136 ± 0.050	0.849 ± 0.545
Mean	17.043 ± 9.680	0.087 ± 0.048	1.888 ± 1.167	0.471 ± 0.287	0.199 ± 0.163	1.096 ± 0.814

Table 3 Monthly average concentrations in the Poyang Lake Migratory Bird Sanctuary excluding samples from Bang Lake

Month	Waters	COD (mg/L)	TP (mg/L)	TN (mg/L)	NH_4^+–N (mg/L)	NO_3^-–N (mg/L)	Chl-a (μg/L)
June	Sha Lake	12.908 ± 2.059	0.085 ± 0.011	0.854 ± 0.647	0.238 ± 0.053	0.112 ± 0.031	1.813 ± 0.457
	Dahu lake	15.714 ± 0.577	0.101 ± 0.012	1.941 ± 0.160	0.299 ± 0.043	0.130 ± 0.020	0.609 ± 0.022
July	Sha Lake	14.314 ± 0.285	0.050 ± 0.006	3.625 ± 0.017	0.298 ± 0.021	0.235 ± 0.089	0.967 ± 0.526
	Dahu Lake	19.676 ± 2.376	0.084 ± 0.020	3.974 ± 0.279	0.254 ± 0.008	0.317 ± 0.118	1.676 ± 0.281
	Xiu River	30.643 ± 3.242	0.062 ± 0.016	3.815 ± 0.324	0.336 ± 0.015	0.250 ± 0.103	0.780 ± 0.467
September	Dahu Lake	19.578 ± 0.602	0.105 ± 0.051	2.467 ± 0.139	0.405 ± 0.140	0.079 ± 0.036	2.146 ± 0.344
	Gan River	7.960 ± 1.573	0.097 ± 0.042	2.134 ± 0.143	0.309 ± 0.027	0.097 ± 0.049	0.841 ± 0.253
	Xiu River	4.766 ± 2.867	0.086 ± 0.054	1.957 ± 0.223	0.245 ± 0.035	0.166 ± 0.050	1.485 ± 0.433
October	Dahu Rake	15.178 ± 1.269	0.105 ± 0.006	2.917 ± 0.311	0.395 ± 0.036	0.076 ± 0.014	2.023 ± 0.127
	Gan River	9.747 ± 1.887	0.339 ± 0.009	4.601 ± 0.566	0.295 ± 0.034	0.400 ± 0.025	0.451 ± 0.265
	Xiu River	5.080 ± 1.088	0.093 ± 0.012	3.577 ± 0.674	0.295 ± 0.048	0.374 ± 0.067	0.514 ± 0.282
April	Gan River	4.738 ± 2.057	0.084 ± 0.029	3.334 ± 0.527	0.542 ± 0.107	0.961 ± 0.141	0.454 ± 0.109
	Xiu River	6.787 ± 4.154	0.071 ± 0.028	3.132 ± 0.653	0.416 ± 0.107	0.339 ± 0.150	0.822 ± 0.128
May	Gan River	28.470 ± 2.336	0.061 ± 0.020	4.332 ± 0.388	0.359 ± 0.241	1.311 ± 0.403	0.161 ± 0.007
	Xiu River	20.832 ± 3.436	0.028 ± 0.023	3.781 ± 0.399	0.510 ± 0.183	0.774 ± 0.198	0.571 ± 0.026

water purification happened gradually due to natural processing of organic matter and water quality in Bang Lake improved.

Starting in June, the water level of the Gan and Xiu Rivers rose and the waters of Bang, Sha, and Dahu Lakes connected with the rivers. In other words, Wucheng became an island and Poyang Lake Migratory Bird Sanctuary was flooded for days at a time, up to 1 month. Connectivity is a decisive component of general ecosystem characteristics and the balance between input and output of nutrients (Schiemer et al. 2006). Water quality in June and July was relatively poor because of increased flow rates, increased disturbance, upstream water pollution, and other factors. From Table 3, the water quality of the Xiu River in July was the worst in the sampling period due to upstream water pollution. At normal water levels, the Xiu River was the cleanest river in the Poyang Lake Basin. The water level of the Gan and Xiu Rivers dropped during September and October and the waters of Bang Lake, Sha Lake, and Dahu Lake gradually separated from each other and from the adjacent rivers, reducing the negative water quality effects of the rivers on Bang Lake.

3.2 Spatial and temporal distribution of water quality & correlation analysis between indexes

The monthly variabilities of concentration distributions of the various physical and chemical indicators in Bang Lake were large, specific distributions were shown in Fig. 3.

Average COD ranged from 6.828 to 25.481 mg/L during the sampling period. COD in April, May, June, September, and October was at the level of a class I water. There was a significant negative correlation between the COD concentration and water level. From September 2012 to March 2013, the water level of Bang Lake progressively lowered and COD concentration increased gradually. With rainfall increasing from April through [what month?], the water level of Bang Lake began to rise, COD concentration generally decreased. The water level kept increasing in June and July; however, the COD concentration had an upward trend for this time period. This trend might be due to the high water level allowing sewage and agricultural irrigation water in the surrounding towns and villages to flow directly into Bang Lake at the beginning of June. Water bodies within the Poyang Lake Migratory Bird Sanctuary wetlands were strongly governed by their hydrological connectivity with the Gan and Xiu Rivers. Except for July, COD concentration variation between the sampling points was relatively stable in each month.

Average TP ranged from 0.039 to 0.121 mg/L. The annual change of TP concentration was smaller and more stable than that of COD. According of the basic standard limits of Chinese Surface Water Quality Standards on TP classification of lake and reservoir projects, Bang Lake reached Class III in May. The water qualities of July, April, October, and December were Class IV; and the water qualities of March, June, and September were Class V.

The differences of monthly average concentrations of TN and the concentrations of TN among sampling points in the same month were large. NH_4^+–N concentrations were stable from June to October. The differences of NH_4^+–N concentration from December to May were large and the concentrations high relative to the rest of the year. Except for July, NO_3^-–N in Bang Lake had a similar trend to NH_4^+–N. Starting in December, the water quality of Bang Lake was affected by migratory birds, with NH_4^+–N and NO_3^-–N concentrations increasing, and was also subject to increased evaporation, further increasing index concentrations. After March, the number of migratory birds significantly declined and their impact weakened. The concentrations of NH_4^+–N and NO_3^-–N began to decrease due to the settlement of suspended solids and the absorption and degradation effects from aquatic plants and animals (Hu et al. 2012).

Chl-a concentration was lower in the wet season than that of in the dry season (March, April except to December), possibly because the water mobility of Bang Lake was high in the wet season. Fast-flowing water produced more suspended solids and reduced light transmission in water, impacting photosynthesis of algae and resulting in the lower concentrations of Chl-a. Light transmission was an important factor affecting photosynthetic efficiency and the degree of eutrophication (Mvungi et al. 2012; Kolada 2014). However the concentrations of NH_4^+–N, NO_3^-–N, and TP of water in the dry season were higher, when the water flow was slower and the water was clearer. The temperature was lower, but having more adequate light, the concentration of Chl-a increased. The lowest Chl-a concentration in December was likely due to the lowest temperature (about 10 °C)

All data were analyzed using SPSS18.0. A normal probability plot (Normal Q–Q Plot) was created based on a list (month as factors, each index as the dependent variable). Each index was not a linear density of each month; the concentrations were not normally distributed. As the monthly average concentrations between each index were not normally distributed, the bivariate Spearman correlation coefficient was used for correlation analysis. The results showed that there was a high correlation among COD, ammonia (NH_4^+–N), and nitrate nitrogen (NO_3^-–N), with a correlation coefficient $r = 0.829$ and statistically significant coefficient $p = 0.042 < 0.05$.

Correlation analysis was performed on the data of each index. It showed significantly weak correlation between COD and NH_4^+–N ($r = 0.325$, $p = 0.001$), and significantly weak correlation between COD and NO_3^-–N ($r = 0.300$, $p = 0.002$).

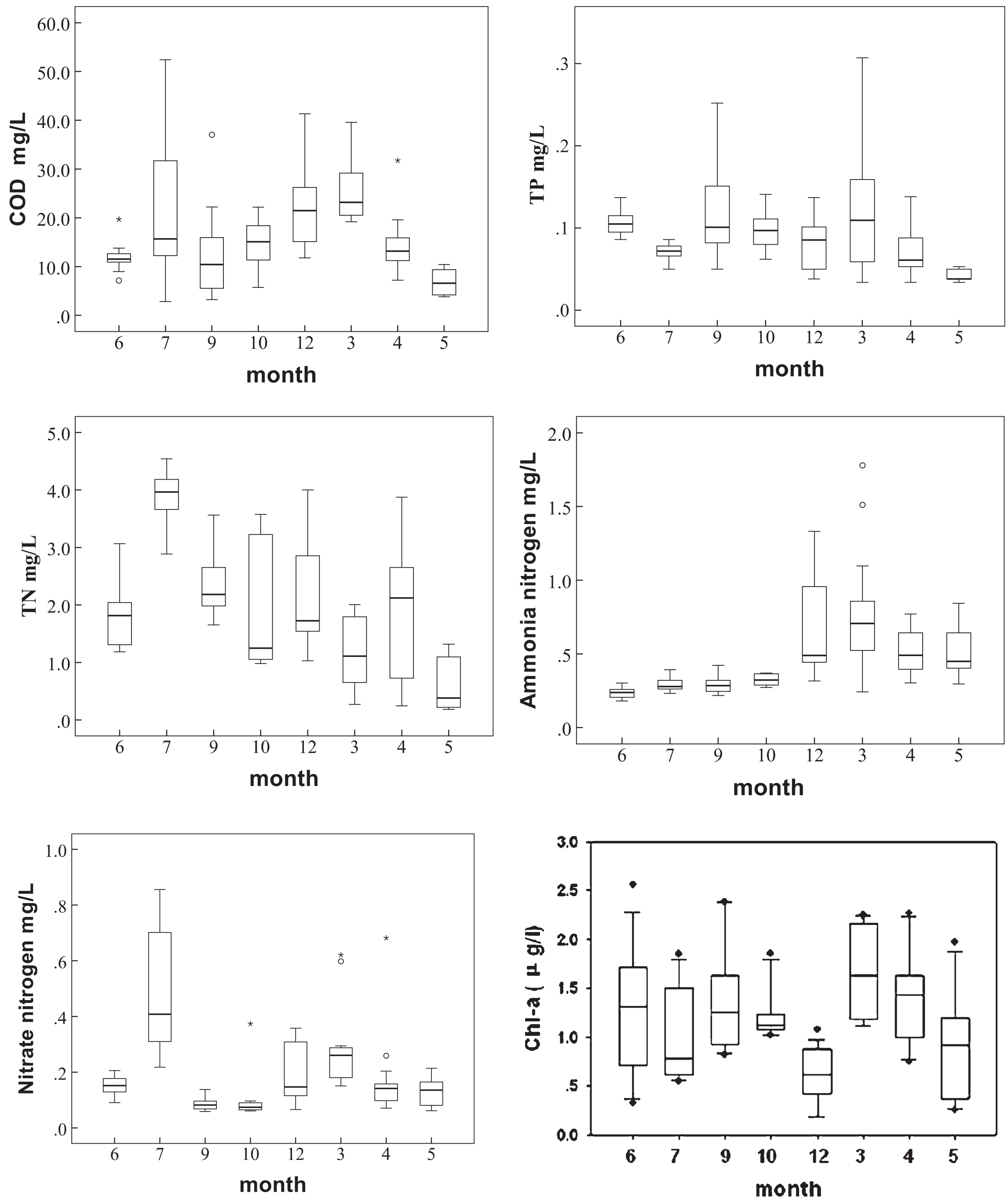

Fig. 3 Concentration distributions in Bang Lake

There were significant weak correlations between TN and TP, between TN and NH_4^+–N, and between TN and NO_3^-–N. The correlation coefficients were 0.286, −0.236, and 0.201 respectively, and there was negative correlation between TN and NH_4^+–N. There was significantly weak correlation between Chl-a and NO_3^-–N($r = 0.233$, $p = 0.026$). From south to north, TN concentration of Bang Lake decreased, while Chl-a trended upward. The concentrations of COD, NH_4^+–N, NO_3^-–N, and Chl-a increased gradually from east to west. Correlations of each index in space were shown in Table 4.

3.3 Water quality assessment

Four of the measured physical and chemical indicators (COD, NH_4^+–N, TN, TP) were selected as evaluation indices. Water quality of Bang Lake was evaluated based on the monthly average concentrations of the index values

Table 4 Concentration correlation on the space of Bang Lake

		COD	TN	TP	NH_4^+–N	NO_3^-–N	Chl-a
Latitude	Correlation coefficient	0.103	−0.280**	0.024	0.152	−0.005	0.401**
	Significant coefficient	0.309	0.003	0.805	0.112	0.959	0.000
Longitude	Correlation coefficient	−0.268**	0.038	−0.033	−0.420**	−0.383**	−0.304**
	Significant coefficient	0.007	0.690	0.792	0.000	0.000	0.003

** $p < 0.01$

Table 5 Chinese surface water quality standards classification values

Evaluation factor	I	II	III	IV	V
COD (mg/L)	15	15	20	30	40
TN (mg/L)	0.2	0.5	1.0	1.5	2.0
TP (mg/L)	0.01	0.025	0.05	0.1	0.2
NH_4^+–N (mg/L)	0.015	0.5	1.0	1.5	2.0

in Table 2. Classification levels of five standard indicators are shown in Table 5. The membership function values of evaluation factors for each month are shown in Table 6.

$$R_1 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.161 & 0.839 \\ 0 & 0 & 0 & 0.62 & 0.38 \\ 0.5464 & 0.4536 & 0 & 0 & 0 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0 & 0 & 0.5516 & 0.4484 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0.3867 & 0.6133 & 0 \\ 0.4227 & 0.5773 & 0 & 0 & 0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0.5267 & 0.4733 \\ 0.4309 & 0.5691 & 0 & 0 & 0 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.048 & 0.952 \\ 0 & 0 & 0.04 & 0.96 & 0 \\ 0.3629 & 0.6371 & 0 & 0 & 0 \end{bmatrix}$$

$$R_5 = \begin{bmatrix} 0 & 0 & 0.5434 & 0.4563 & 0 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 0.28 & 0.72 \\ 0 & 0.3168 & 0.6832 & 0 & 0 \end{bmatrix}$$

$$R_6 = \begin{bmatrix} 0 & 0 & 0.3013 & 0.6987 & 0 \\ 0 & 0 & 0.299 & 0.701 & 0 \\ 0 & 0 & 0 & 0.54 & 0.46 \\ 0 & 0.2355 & 0.7645 & 0 & 0 \end{bmatrix}$$

$$R_7 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.125 & 0.875 \\ 0 & 0 & 0.3333 & 0.6667 & 0 \\ 0 & 0.4914 & 0.5086 & 0 & 0 \end{bmatrix}$$

$$R_8 = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.6063 & 0.3937 & 0 & 0 \\ 0 & 0.275 & 0.725 & 0 & 0 \\ 0.392 & 0.607 & 0 & 0 & 0 \end{bmatrix}$$

The weights of each index were as follows: $w_1 = (0.1239\ \ 0.3823\ \ 0.4449\ \ 0.0489)$, $w_2 = (0.3407\ \ 0.1215\ \ 0.4453\ \ 0.0925)$, $w_3 = (0.1092\ \ 0.4145\ \ 0.4252\ \ 0.0511)$, $w_4 = (0.1484\ \ 0.3943\ \ 0.3918\ \ 0.0654)$, $w_5 = (0.1995\ \ 0.3864\ \ 0.2885\ \ 0.1256)$, $w_6 = (0.2266\ \ 0.2136\ \ 0.4233\ \ 0.1366)$, $w_7 = (0.1544\ \ 0.4075\ \ 0.3260\ \ 0.1121)$, $w_8 = (0.1612\ 0.2432\ 0.3684\ 0.2272)$. The fuzzy relation matrix and index weights were calculated by Eq. 4 and the results are presented in Table 7.

Table 7 shows that water quality of Bang Lake was poor during the sampling period. The water quality of Bang Lake in the most of sampled months was level IV or V, except in May when it was II. From the value of membership function evaluation factors showed in Table 6, the concentration of TN in Bang Lake was the determining factor of water quality. The other three evaluation factors in order of decreasing impact were TP, NH_4^+–N, and COD.

After March, the impact on the water body of Bang Lake from migratory birds was weakened, and, with rainfall increasing in April, the water level of Bang Lake began to rise, COD, NH_4^+–N, and NO_3^-–N tended to decrease. These factors contributed to the water quality of Bang Lake improving in May. At the beginning of June, sewage and agricultural irrigation water in the surrounding towns and villages flowed directly into Bang Lake from the Gan and Xiu Rivers, which led to water quality deterioration in Bang Lake.

4 Conclusion

The annual change of Bang Lake water quality in Poyang Lake Migratory Bird Sanctuary was large and the water quality was generally poor. Water quality of Bang Lake was slightly worse than that of Sha Lake and Dahu Lake in the wet period, but better in the normal water season. Water bodies within the Poyang Lake Migratory Bird Sanctuary wetlands were strongly governed by their hydrological connectivity with Gan and Xiu Rivers. During the dry season, the water quality of Bang Lake became deteriorated due to migratory birds' disruption and feces. There were high correlations among COD, NH_4^+–N, and NO_3^-–

Table 6 Monthly membership function values

Evaluation factor	$u_1(x)$	$u_2(x)$	$u_3(x)$	$u_4(x)$	$u_5(x)$	$u_1(x)$	$u_2(x)$	$u_3(x)$	$u_4(x)$	$u_5(x)$
	June					July				
COD	1	0	0	0	0	0	0	0.5516	0.4484	0
TN	0	0	0	0.161	0.839	0	0	0	0	1
TP	0	0	0	0.62	0.38	0	0	0.3867	0.6133	0
NH_4^+–N	0.5464	0.4536	0	0	0	0.4227	0.5773	0	0	0
	September					October				
COD	1	0	0	0	0	1	0	0	0	0
TN	0	0	0	0	1	0	0	0	0.048	0.952
TP	0	0	0	0.5267	0.4733	0	0	0.04	0.96	0
NH_4^+–N	0.4309	0.5691	0	0	0	0.3629	0.6371	0	0	0
	December					March				
COD	0	0	0.5437	0.4563	0	0	0	0.3013	0.6987	0
TN	0	0	0	0	1	0	0	0.299	0.701	0
TP	0	0	0.28	0.72	0	0	0	0	0.54	0.46
NH_4^+–N	0	0.3168	0.6832	0	0	0	0.2355	0.7645	0	0
	April					May				
COD	1	0	0	0	0	1	0	0	0	0
TN	0	0	0	0.125	0.875	0	0.6063	0.3937	0	0
TP	0	0	0.3333	0.6667	0	0	0.275	0.725	0	0
NH_4^+–N	0	0.4914	0.5086	0	0	0.392	0.607	0	0	0

Table 7 Results of fuzzy comprehensive evaluation

Evaluation samples	$B_i = w_i \bullet R_i$					Evaluation rank
June	0.1506	0.0222	0	0.3374	0.4898	V
July	0.0391	0.0534	0.3601	0.4259	0.1215	IV
September	0.1312	0.0291	0	0.224	0.6157	V
October	0.1722	0.0417	0.0157	0.3951	0.3753	IV
December	0	0.0398	0.2751	0.2987	0.3864	V
March	0	0.0322	0.2365	0.5366	0.1947	IV
April	0.1544	0.0551	0.1657	0.2686	0.3565	V
May	0.1701	0.3867	0.3628	0	0	II

N in terms of the correlation of monthly average concentrations of each index. Spatial variation showed that TN concentration in Bang Lake decreased and Chl-a increased from south to north. The concentrations of COD, NH_4^+–N, NO_3^-–N, and Chl-a increased gradually from east to west. Fuzzy comprehensive analysis showed that the water quality of Bang Lake was at the level of class IV and V in general and that the main factor determining the water quality of Bang Lake was TN.

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