Research on the Spatio-Temporal Characteristics of Water Quality and the Pollutant Fluxes Relationship Between Chaohu Lake and its Tributaries

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Abstract. Based on the water quality data of 17 monitoring sections in Chaohu Lake and its tributaries in Chaohu Lake and its main tributaries in 2022,the water quality was evaluated by the WQI integrated water quality index and the spatio-temporal distribution characteristics of water quality was analyzed by the cluster method to fully grasp the water environment condition. Through quantitative analysis of pollutant flux, the contribution rate of pollution and water quality between rivers and lakes were studied. The result showed that the average WQI of the monitoring section of Chaohu Lake and the tributaries was 72.0, and the evaluation grade was "good". The spatio-temporal clustering showed significant water period characteristic in time, and east-west spatial differences of the lake and the north-south spatial differences of the tributaries. The Hangbu River and the Nanfei River were the main contributors to the pollutant fluxes entering the lake. There were correlations between the lake sections and the river sections. The results could provide a certain reference for the water quality management of Chaohu Lake.

Keywords: spatio-temporal characteristics; pollutant fluxes; water quality relationship

1 Introduction

Lakes are relatively closed areas of water accumulation in land depressions, the recharge of lake water mainly includes three aspects: surface runoff into the lake, lake surface precipitation and groundwater underflow. As environmental governance continues to promote, the point source pollution directly discharged into the lake has been basically controlled, and the industrial wastewater, agricultural water and domestic sewage carried by the rivers entering the lake have become the main sources of pollution affecting the water quality of the lake. When the sewage flowing into the lake exceeds the self-purification capacity of the lake, the water quality of the lake changes, which deteriorates the lake environment and causes environmental problems such

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as eutrophication, organic pollution, and blooms. Many scholars have carried out research on the relationship between river and lake water quality. Ran Jiao et al. [1] revealed the water quality characteristics of the rivers entering the lake and their responses to the water quality in the lake area based on the water quality monitoring data of the rivers and lakes in the Qionghai Sea. Yan Chunli et al.[2] discussed the characteristics of pollution change of rivers entering the lake in the northern part of Erhai Lake and their impact on the northern lake area by analysing the monitoring data of the Luoshi River, Mitho River, Yong'an River and the northern lake area of Erhai Lake in 2016~2018. Zhong Jingjing et al. [3] studied the correlation between the rivers entering the lake and the water quality of the Taihu Lake through the analysis of the water quality of the main observation sections in the Taihu Lake Basin. However, there are still few detailed reports and studies on the relationship between pollutant fluxes and water quality of rivers and lakes.

Chaohu Lake is located in the central part of Anhui Province and the left bank of the lower reaches of the Yangtze River, and is one of the five largest freshwater lakes in China. In recent years, the environmental management of Chaohu Lake has achieved remarkable results, and the pollutant inputs from the rivers entering the lake are still the key to the water quality control of Chaohu Lake due to the spatial continuity between the rivers and the lake. Wu Li et al. [4] studied the distribution characteristics of water environment factors in the river and lake system by analysing the water quality parameters of Chaohu Lake and the rivers entering the lake; Mao Mao Guangjun et al. [5] studied the effect of pollutant transport in the tributaries of the river on the water quality of Chaohu Lake.

In order to comprehensively understand the overall situation, spatial and temporal characteristics of the water quality of Chaohu Lake and the main rivers around the lake and the relationship between the water quality of the river and lake, this paper adopts the WQI comprehensive water quality index to evaluate the water quality of Chaohu Lake and the rivers around the lake, and explores the correlation between the input of pollutants and the water quality of rivers and lakes on the basis of studying the temporal and spatial distribution characteristics of water quality, with the aim of providing scientific support for the comprehensive management of water environment in Chaohu River and Lake System.

2 Methodology

2.1 Study Area and Data Sources

The study area of this paper includes Chaohu Lake and the main tributaries around the lake. Chaohu Lake is 54 km long from east to west and 21 km long from north to south, with geographic coordinates of 117°17′~117°52′ east longitude and 31°25′~31°43′ north latitude, belonging to the water system on the left bank of the Yangtze River, and the average water depth of the lake is about 3.39 m. The lake area is about 780 km² when the water level of Chaohu Lake is 9.0m(Wusong Elevation). The main rivers entering the lake include 8 rivers, which are Nanqi River, Shiwuli River, Pai River, Hangbu River, Baishishan River, Zhao River, Shuangqiao River, Zhegao River, accounting for more than 90% of the water entering the lake. The main river out of the lake is Yuxi River. This paper collects the monthly water quality data from 8 water quality monitoring sections in Chaohu Lake and 9 water quality monitoring sections in the tributaries in 2022, and the average monthly inflow (outflow) of the tributaries. The water system and water quality monitoring section of Chaohu Lake are shown in Fig. 1.

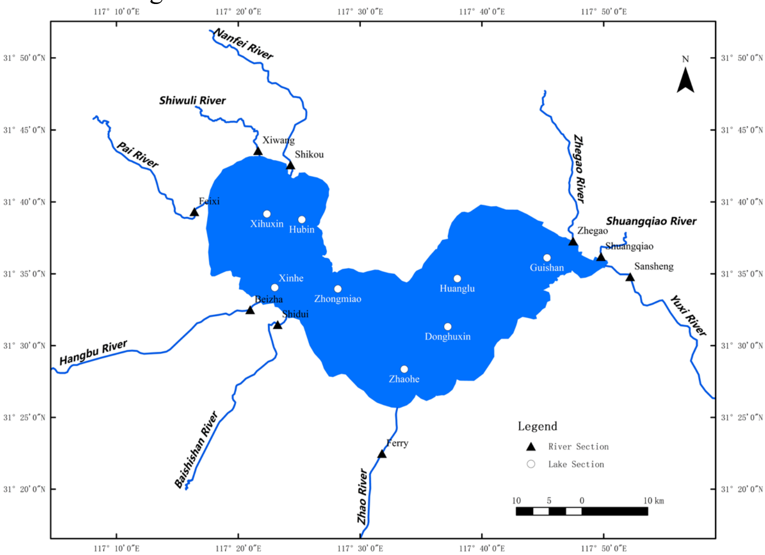

Fig. 1. Research area and the water quality monitoring sections

2.2 Research Methods

The WQI composite water quality index integrates the evaluation results of individual water quality parameters, which can better reflect the overall results of the overall water quality condition, and has been widely used in the evaluation of surface water and groundwater quality due to its strong operability and high evaluation efficiency. The calculation of the WQI index is based on the results of KOCER et al. [6], and the formula is as follows:

$$\mathrm{WQI} = \frac{\sum_{i=1}^{n} C_i P_i}{\sum_{i=1}^{n} P_i} \tag{1}$$

Where: n is the total number of water quality parameters evaluated, C_i is the value assigned to parameter i after normalization;P_i is the relative weight assigned to each parameter;the valid values of C_i and P_i, and grading of WQI refer to the results of NONG X Z, et, al.[7]. The distribution range of WQI values is between 0-100, and the water quality evaluation grade is divided into 5 levels according to the WQI value, which are excellent(WQI>90), good(70<WQI≤90), moderate(50<WQI≤70), fair(25<WQI≤50),poor(WQI≤25).

The pollutant flux calculation is based on the results systematically summarized by numerous scholars [8-9], and the calculation formula is as following:

$$F_{\mathrm{mi}} = C_{\mathrm{i}} \times Q_{\mathrm{i}} \tag{2}$$

where: F_{mi} is the calculation of the monthly pollutant flux of the section, C_i is the concentration value of a certain pollution factor in the i month of the section, Q_i is the monthly runoff of the section.

The Ward method hierarchical clustering is used to analyze the clustering of water quality parameters in each month and monitoring sections, and the clustering results were used to explore the spatial and temporal distribution characteristics of water quality. The Pearson correlation coefficient was used to analyze the correlation between river and lake water quality. The above tasks were completed via SPSS software.

3 Results & Discussion

3.1 Spatiotemporal Characteristics of Water Quality

Overall Water Quality Status.

The results of WQI calculation showed in Fig. 2 indicated that in 2022, the WQI values of 17 monitoring sections in Chaohu Lake and the rivers around the lake ranged from 42.27 to 85.91, and the average value of the overall WQI was 72.0, and the overall evaluation of water quality was "good". The WQI values of 8 monitoring sections in the lake area ranged from 61.36 to 85.91, and the corresponding water quality grades covered two levels: "medium" and "good". The WQI value of each monitoring section of the river around the lake ranged from 42.27 to 82.27, and the water quality grade covered three levels: "fair", "moderate" and "good". The WQI value of the Shikou section which is at the entrance of Nanfei River into the lake is significantly lower than that of other sections, and the water quality grade is poor. The monthly WQI values of the Huanglu and Hubin sections in the lake area changed significantly more than those in other sections, that is, the monthly water quality of the two sections fluctuated greatly. Overall, the variation range of the monthly WQI value of each section of the river is greater than that of the lake section, indicating that the water quality of the lake area is more stable than that of the river.

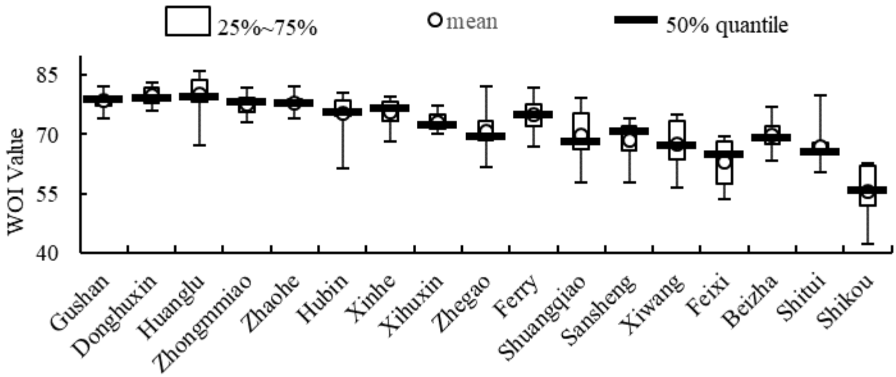

Fig. 2. Statistical chart of WQI value of each monitoring section

Temporal and Spatial Variation Characteristics of Water Quality

The monthly water quality parameters of 17 stations in 2022 were clustered in time and space. The results showed that the water quality was divided into three categories in time, the first category contained January-May, the second category contained October-December, and the third category contained June-September, and the time clustering results were similar to those of the water period (flood season, flat water period, dry season). It can be seen that the water quality of Chaohu Lake and its tributaries has a certain correlation with the water period, and especially the influence of the flood season is very obvious

The spatial clustering results of the lake showed that the water quality in space presents east-west differences in lake area. The sections in the eastern part of the lake area are clustered into one category, the sections in the central part of the lake area are clustered into one category, and the sections in the western part of the lake area are clustered into one category.

The spatial clustering results of rivers divided into three categories. The rivers in the south are grouped together, the large rivers in the north are grouped together, and the small rivers in the north are also grouped together, with significant differences between the north and south.

3.2 Analysis of the Relationship Between River and Lake Water Quality

Estimation of Pollutant Flux and Analysis of Contribution Rate

In 2022, the total inlet water volume of the eight major inlet rivers of Lake Chaohu was 268.801 million m^3, and the percentage of inlet flow of each river is shown in Fig. 3. Based on the monthly measured flow of the inlet rivers and the monthly pollutant concentration, the pollutant fluxes of each inlet river were calculated (Table 1).

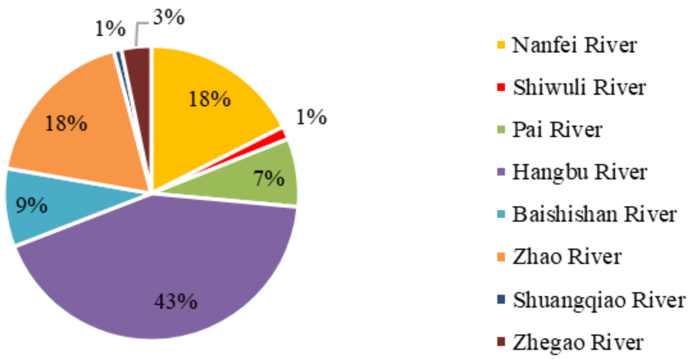

Fig. 3. The proportion of water flowing into Chaohu Lake in 2022

Table 1. Pollutant fluxes in major rivers entering the lake in 2022

River Name	COD_{Mn}		BOD_5		NH_3-N		TN		TP		COD_{Cr}	
	Fluxes	%	Fluxes	%	Fluxes	%	Fluxes	%	Fluxes	%	Fluxes	%
Zhegao River	31	3.51	20	3.42	3	2.73	13	1.91	1	3.7	128	4.09
Zhao River	176	19.93	78	13.33	5	4.55	73	10.7	3	11.11	622	19.88
Shuangqiao River	6	0.68	3	0.51	0.4	0.36	4	0.59	0.1	0.37	24	0.77
Shiwuli River	12	1.36	5	0.85	2	1.82	16	2.35	0.3	1.11	45	1.44
Pai River	74	8.38	47	8.03	13	11.82	74	10.85	2	7.41	190	6.07
Hangbu River	347	39.3	289	49.4	26	23.64	213	31.23	13	48.15	1147	36.67
Baishishan River	79	8.95	32	5.47	11	10	54	7.92	1	3.7	266	8.5
Nanfei River	158	17.89	111	18.97	49	44.55	235	34.46	7	25.93	705	22.54
Total into the lake	883	100	585	100	110	100	682	100	27	100	3128	100
Yuxi River(Out of the lake)	-1029	/	-369	/	-125	/	-500	/	-21	/	-4249	/
Net fluxes	-146	/	216	/	-15	/	182	/	6	/	-1121	/

Note: Fluxs is measured in tons

Hangbu River is the largest river into the lake, so its pollutant flux into the lake is large, and the fluxes of COD_{Mn}, BOD_5 and COD_{Cr} were the largest among all rivers entering the lake, and the proportion of these three pollutants was equivalent to the proportion of water volume into the lake, while the proportion of TN and NH_3-N flux was slightly lower than that of water volume. The water inflow of the Nanfei River is the second, but its NH_3-N, TN and TP pollutant fluxes are the largest among all the rivers entering the lake, especially the NH_3-N flux accounts for 44.55%, reflecting the large contribution rate of the Nanfei River to the N and P aspects of Chaohu Lake. The volume of water entering the lake of Zhao River is comparable to that of the Nanfei River, but its pollutant fluxes are all smaller than that of the Nanfei River, especially the fluxes of NH_3^-N, TN, and TP are significantly lower than that of the Nanfei River, and the contribution of NH_3-N and TN fluxes is much lower than that of water volume. The proportion of water volume into the lake and pollutant flux in the rest of the rivers is relatively close. From the calculation results, it can be seen that the Hangbu River and the Nanfei River are the main contributors to the pollutant flux of Chaohu Lake, so special attention should be paid to these two rivers in the water quality management of the lake area.

Yuxi River is the outflow river of Chaohu Lake, which is connected with Yangtze River, and the pollutant fluxes exported to Chaohu Lake through the cross section of Sansheng brigade of Yuxi River in 2022 is 1029t for $COD_{Mn,}$ 369t for BOD_5, 125t for NH_3-N, 21t for TP, 4249t for COD_{Cr}. According to the inlet and outlet fluxes of the lake, the net pollutant fluxes of Chaohu Lake in 2022 is -146t for COD_{Mn}, 216t for BOD_5, -15t for NH_3-N, 182t for TN, 6t for TP, and -1121t for COD_{Cr}. It can be seen that the 3 indicators of COD_{Mn}, NH_3-N and COD_{Cr} are net outflows in 2022, and the 3 indicators of BOD_5, TN and TP are net inflows. Generally BOD_5 can be decomposed by microorganisms, which require oxygen consumption to decompose BOD_5 in water. The DO indicators in the lake area is good, so BOD_5 is basically at the level of Class I~II water of Environmental Quality Standard for Surface Water (GB3838-2002). Among the above three net inflow indicators, the main exceeding factors in the lake area are TN and TP. In water quality management in the lake area, particular attention should be paid to the input of nitrogen and phosphorus.

Correlation Analysis of River and Lake Water Quality.

Correlation analysis was conducted between the WQI values of the lake area section and the river section. Pearson correlation coefficient in Table 2 showed that the WQI value of Guishan section in the lake area was extremely significant correlated with the WQI value of Zhegao section where Zhegao river entering to the lake, and significant correlated with the WQI values of Beizha and Shidui section where Hangbu River and Baishishan River entering to the lake. The WQI value of Donghuxin was extremely significant correlated with that of Beizha section where Hangbu River entering to the lake. The WQI value of Huanglu section was extremely significant correlated with that of Zhegao section where Zhegao River entering to the lake, and significant correlated with the WQI value of Feixi and Shikou section where Pai River and Nanfei River entering to the lake. The WQI value of the Hubin section was extremely significant correlated with that of Shikou section. The WQI value of Xinhe section was extremely significant correlated with that of Ferry section where Zhao River entering to the lake, and significant correlated with the WQI value of Beizha section. There were no significant correlation between Zhongmiao, Zhaohe, Xihuxin sections, and the river sections.

Table 2. The Pearson correlation coefficient of WQI between the lake and river sections

River sectin / Lake section	Zhegao River	Zhao River	Shuangqiao River	Shiwuli River	Pai River	Hangbu River	Baishishan River	Nanfei River
	Zhegao	Ferry	Shuangqiao	Xiwang	Feixi	Beizha	Shidui	Shikou
Guishan	0.836**	0.623*	0.394	-0.057	0.517	0.675*	0.695*	0.573
Donghuxin	0.005	0.252	0.276	-0.183	-0.251	0.715**	0.089	0.024
Huanglu	0.817**	0.418	0.153	0.21	0.687*	0.551	0.479	0.627*
Zhongmiao	0.336	0.589	-0.054	0.125	-0.056	0.345	0.047	-0.087
Zhaohe	0.307	0.405	-0.256	0.07	-0.075	0.42	-0.161	-0.254
Hubin	0.577	0.259	0.403	-0.004	0.463	0.513	0.479	0.855**
Xinhe	0.349	0.716**	0.129	-0.01	-0.101	0.638*	0.312	0.034
Xihuxin	0.125	0.485	0.493	-0.18	-0.138	0.321	0.256	0.306

Note: ** indicates extremely significant correlation ($P<0.01$): * indicates significant correlation ($P<0.05$)

4 Conclusions

(1) The WQI values of the monitoring sections in the Chaohu Lake area and surrounding rivers in 2022 ranged from 42.27 to 85.91, with an overall average WQI of 72.0, and the overall water quality evaluation grade was "good". The water quality level corresponding to the monitoring section in the lake area covers two levels: "medium" and "good"; The water quality levels of the monitoring sections for the rivers surrounding the lake cover three levels: "general", "moderate", and "good". The water quality in the lake area is more stable than that of the river.

(2) There are obvious water quality characteristics in the lake area and surrounding rivers over time (monthly scale), especially during the flood season when the water quality shows significant differences compared to other water periods. During the flood season, the WQI value is lower and the water quality is relatively poor. Special attention should be paid to water quality management in the lake area during the flood season. The water quality in the lake area shows east-west spatial differences, while the water quality of rivers around the lake shows southern differences, and the WQI of larger rivers in the north is significantly lower than other rivers, which should be taken seriously in management.

(3) The main contributors to the pollutant flux entering the lake in 2022 are Hangbu River and Nanfei River. The pollutants in the Chaohu Lake area mainly flow out through Yuxi River. The three indicators of CODmn, NH3-N, and CODCr for the whole year are net outflows, and the three indicators of BOD5, TN, and TP are net inflows. The main exceeding factors in the lake area are TN and TP. In terms of water quality management, the rivers entering the lake should focus on the Hangbu River and Nanfei River; Water quality parameters should focus on TN and TP indicators.

(4) The WQI values of the Guishan section in the lake area are significantly correlated with the WQI values of the Zhegao River entering the lake section, the WQI values of the eastern half of the lake center section are significantly correlated with the WQI values of the Hangbu River entering the lake section, the WQI values of the Huanglu section are significantly correlated with the WQI values of the Zhegao River

entering the lake section, the WQI values of the lakeside section are significantly correlated with the WQI values of the Nanfei River entering the lake section, and the WQI values of the Xinhe entering the lake area section are significantly correlated with the WQI values of the Zhaohe entering the lake section. The above correlation analysis results can provide reference for the management of river and lake water quality systems.

References

1. RAN Jiao, XIAO Keyan, XIANG Rong, et al. Water quality characteristics of inflow rivers in Lake Qionghai and its responding relationship with the lake region,2011-2021*[J]. *J. Lake Sci.*,2023,35(6):1960-1969.
2. YAN Chunli, ZHAO Ming, LI Zekun, et al. Water characteristics of inflow rivers in northern Erhai Lake and their impact on the northern lake area[J]. ENVIRONMENTAL ENGINEERING, 2020, 38(12): 59-63,5.
3. ZHONG Jingjing, LIU Maosong, WANG Yu, et al. Spatial correlation of major water quality indices between the lake and rivers in Taihu Lake Basin[J]. Journal of Hydroecology, 2014,33(8):2176-2182.
4. WU Li, ZHANG Yan, CHEN Yajun, et al. Distribution of Water Environmental Factors and Evaluation of Trophic State in the River-Lake System of Chaohu Lake Basin[J]. Journal of Hydroecology, 2023,44(1): 65-72.
5. Mao Guangjun, Yang libiao, Yan Weijin, et al. The Influence of Pollutant Inputs from the Major Tributaries on Water Quality of Chao Lake [J].Journal of Arao-Environment Science, 2014,33(1):141-147.
6. KOCER M A T, SEVGILI H. Parameters selection for water quality index in the assessment of the environmental impacts of landbased trout farms[J].Ecological Indicators,2014,36:672-681.
7. NONG X Z,SHAO D G,ZHONG H, et al. Evaluation of water quality in the South-to-North Water Diversion Project of China using the water quality index (WQI) method[J].Water Research,2020,178:115781.
8. Chen Y C, Lung W S, Yang H C, et al. Pollutant flux estimation in an estuary comparison between model and field measurements[J].Environments,2014,1(1):107-123.
9. GUO Chaochen, LEI Kun, LI Xiaoguang, et al. Spatiotemporal Variation Characteristics of Main Pollutant Fluxes in the Yangtze River Basin from 2017 to 2020[J]. Environmental Science, 2023, 44(8): 4279-4291.