Asia Pacific Academy of Science Pte. Ltd.

Pollution Study 2023, 4(2), 2068.
https://doi.org/10.54517/ps.v4i2.2068

Article

Characteristics of water quality and estimation of pollution loads in the main rivers surrounding Erhai Lake

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CITATION

Huang M. Characteristics of water quality and estimation of pollution loads in the main rivers surrounding Erhai Lake. Pollution Study. 2023; 4(2): 2068.
https://doi.org/10.54517/ps.v4i2.2068

ARTICLE INFO

Received: 03 July 2023
Accepted: 30 July 2023
Available online: 09 August 2023

Abstract: To uncover the pollution characteristics of the main rivers flowing into Erhai Lake, a study was conducted from January 2014 to December 2016, monitoring the water quality and quantity of 27 major rivers using total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH3-N), and chemical oxygen demand (CODcr) as pollution indicators. Additionally, this study combined an analysis of precipitation data during the same period with water quality monitoring data from the lake area, detailing the water quantity and quality characteristics of the rivers entering the lake, estimating the pollution load entering the lake, and assessing the impact of this pollution load on the lake's water quality. The results indicate that: a) from 2014 to 2016, the total water inflow from the 27 main rivers into the lake ranged from 287 million to 474 million m^3, with the inflow during the flood season accounting for 79.17%, 74.90%, and 61.96% of the annual total, respectively. The water inflow into the lake was positively correlated with the basin's precipitation; b) over time, pollutant concentrations exhibited a fluctuating trend, initially increasing and then decreasing throughout the year. Generally, water quality during the rainy season was good, and the spatial variation in pollutant concentrations was less pronounced than the temporal variation, with a significant negative correlation between pollutant concentrations and basin rainfall; c) the pollution load entering Erhai Lake initially decreased, then increased, and subsequently decreased again over the year. The pollution load was primarily influenced by water volume, with contribution rates ranked as north bank > west bank > southeast bank. The total nitrogen input from the rivers was positively correlated with the total nitrogen concentration in the lake area, while total phosphorus input was positively correlated with the total phosphorus concentration in the lake area, indicating that these rivers are significant sources of nitrogen and phosphorus for Erhai Lake.

Keywords: rivers entering the lake; water quantity and quality; pollution load; Erhai

1. Introduction

When the elevation of Erhai Lake is 1966 m, the North-South length of the lake is 42.5 km, the maximum width from east to west is about 8.4 km, and the average width is 6.3 km; the maximum water depth of Erhai Lake is 21.3 m, the average water depth is 10.6 m, the lake surface area is 252.91 km^2, the island degree is 0.31%, and the water storage capacity is 2.794 billion m^3. The morphological characteristics of the lake basin are 0.10, the development coefficient of the lake shoreline is 2.07, the length of the lake shoreline is 127.85 km, and the lake recharge coefficient is 10.43. It is one of the new three lakes defined by the Ministry of ecological environment [1,2]. The river entering the lake refers to the water flow that flows along the narrow and long depression frequently or intermittently and finally enters the lake under the supply of surface water and groundwater in a certain area [3]. The river entering the lake is the supply channel of important water resources of Erhai Lake and the basic guarantee of water quantity and quality of Erhai Lake [4,5]. As a product of human activities, land use changes the hydrological cycle, soil and water loss, nutrient migration and transformation and other ecological processes of the basin, and then has a spatial and temporal change impact on the river ecological environment [6,7]. There are 117 rivers and streams in Erhai Lake Basin, with a total runoff area of 2565 km^2 and an annual average of 817 million m^3. Among them, there are 27 main rivers entering the lake, accounting for 90.98% of the total water flow of rivers entering the lake [8]. The main rivers around Erhai Lake are: 19 Cangshan Shibaxi and Zongshu rivers on the West Bank, 4 Luoshi River, Xizha River, maiju River and Yong'an River on the north bank, and 4 Fengweiqing, Yulong River, Baita River and BOLUO River on the southeast bank.

Xiang et al. [9] studied the impact of the water quality of rivers entering the lake on the water quality of Erhai Lake in 2014 and the change characteristics of water quality driven by land use. The research results show that there are temporal and spatial differences in the water quality entering the lake, and the overall water quality is poor in the rainy season. Yan et al. [10] analyzed the water quality data of the north three rivers and North Lake area of Erhai Lake from 2016 to 2018, and found that the north three rivers showed typical agricultural non-point source pollution characteristics, and the primary pollutant was total nitrogen. Ma [11] monitored and evaluated the water quality of Shibaxiqing estuary and lake inlet in Cangshan in June, August and November 2009 respectively. Tao et al. [12] calculated the change of water volume based on the survey data of 18 streams in Cangshan from 2004 to 2009. In order to improve the water environment quality of the main rivers entering Erhai Lake, timely grasp the water quality of Erhai Lake and the main rivers entering Erhai Lake, and increase the monitoring and evaluation of the water quality of Erhai Lake and its main rivers entering Erhai Lake, the office of Erhai Lake Protection and treatment leading group of Dali Prefecture has prepared the work plan for monitoring and evaluation of the water quality of Erhai Lake and its main rivers entering Erhai Lake. This study is based on the concentration data of pollutants (total nitrogen, total phosphorus, ammonia nitrogen and chemical oxygen demand) at the inlets of 27 main rivers around Erhai Lake from 2014 to 2016 in the monitoring scheme of rivers entering Erhai Lake, combined with the analysis and research of water inflow, watershed precipitation and lake water quality data in the same period, in order to explore the variation law of pollutant concentration in different water periods, then estimate the pollution load into the lake and evaluate the impact of pollution load on lake water quality, it provides a reference for the protection and treatment of Erhai Lake and the ecological restoration of the river channel entering the lake.

2. Data and methods

2.1. Research methods

According to the work plan for water quality monitoring and evaluation of Erhai Lake and its main rivers entering the lake, 11 monitoring points are set in Erhai Lake area, and 27 monitoring points are set at the mouth of the main rivers entering the lake around Erhai Lake (see **Figure 1**). Collect water samples from the lake area and the entrance of the lake around the 10th day of each month, measure the concentrations of four pollutants: total nitrogen (alkaline potassium persulfate digestion UV spectrophotometry), ammonia nitrogen (Nessler reagent spectrophotometry), total phosphorus (ammonium molybdate spectrophotometry) and chemical oxygen demand (use PA digestion colorimetry), and collect the water inflow into the lake and precipitation data in the basin in the same period.

Figure 1. Monitoring points of Erhai Lake and 27 tributaries.

2.2. Data processing

The annual pollution load (W_j) of the river is calculated by the period flux calculation method, and the formula is:

$$W_j = \sum_{i=1}^{12} C_i \cdot Q_i \cdot 10^{-6} \tag{1}$$

The calculation formula of total annual pollution load (W) is:

$$W = \sum_{j=1}^{27} W_j \tag{2}$$

where: C_i is the instantaneous concentration of the j River in i month, mg/L; Q_i is the inflow of the j River in i month, m^3; W is pollution load, t.

SPSS and Excel software are used for data statistical analysis.

3. Result analysis

3.1. Water volume characteristics of main rivers around Erhai Lake

The water resource characteristics of the main rivers around Erhai Lake are mainly affected by atmospheric precipitation, and secondly closely related to the water interception of the river. The coastal water resources are mainly used in three forms: drinking water for human and livestock, water for enterprises and institutions and agricultural irrigation water. From 2014 to 2016, the total water inflow of 27 main rivers into the lake was 366 million m^3, 287 million m^3 and 474 million m^3 respectively, and the precipitation of the basin in the same period was 627~884 mm. According to the analysis results of monthly water inflow and precipitation from 2014 to 2016 (see **Figure 2**), the water inflow and precipitation in the year showed a single peak trend, mainly concentrated in the flood season (June to October). From 2014 to 2016, the amount of water entering the lake in flood season accounted for 79.17%, 74.90% and 61.96% of the annual amount of water entering the lake respectively, and the precipitation in flood season accounted for 90.43%, 83.40% and 77.15% of the annual precipitation respectively, indicating that the precipitation in this period largely determines the annual precipitation The minimum amount of water entering the lake occurs from February to may, which is also the high incidence period of river closure; the peak value of water entering the lake occurs from July to September, which completely coincides with the month of maximum precipitation in the basin. There is a positive correlation between water entering the lake and precipitation in the basin. From 2014 to 2016, the four rivers with the largest annual water inflow of Erhai Lake are Miju River, Yong'an River, Luoshi River and Xizha River, with annual average water inflow of 13,556,000 m^3, 44,130,000 m^3, 3,658,000 m^3 and 2,794,000 m^3 respectively.

3.2. Water quality characteristics of main rivers around Erhai Lake

On the time scale, the pollutant concentration shows a fluctuating trend of first increasing and then decreasing in the whole year (see **Figure 3**). Under the scouring action of the initial rainfall, a large number of pollutants accumulated in the dry season are brought into the water body and enter the river with the surface runoff. Therefore, the concentration of pollutants in the rivers entering the lake is high when entering the flood season (June). After entering the flood season (July~October), after the scouring of the initial rainfall, the pollution load around the river bank is reduced, the concentration of pollutants in the rivers entering the lake is also greatly reduced, which is in a low concentration state, and the water quality in the rainy season is generally good [13,14]. From 2014 to 2016, the average concentration of chemical oxygen demand was (13.7 ± 4.3) mg/L, (15.9 ± 5.7) mg/L and (11.9 ± 2.9 mg/L) respectively; the peak value in 2014 and 2015 appeared in June, and the maximum value in 2016 appeared in May. From 2014 to 2016, the average concentration of ammonia nitrogen was (0.434 ± 0.114) mg/L, (0.636 ± 0.283) mg/L and (0.458 ± 0.142) mg/L respectively; the peak value in 2014 appeared in May, 2015, and the maximum value in 2016 appeared in April. The mean values of total phosphorus concentrations from 2014 to 2016 were (0.163 ± 0.038) mg/L, (0.199 ± 0.093) mg/L and (0.138 ± 0.031) mg/L respectively; the peak value in 2014 appears in June, the maximum value in 2015 appears in April, and the peak value in 2016 appears in May. From 2014 to 2016, the average concentration of total nitrogen was (2.212 ± 0.277) mg/L, (2.412 ± 0.553) mg/L and (2.425 ± 0.557) mg/L respectively; the peak value in 2014 and 2016 appeared in December, and the maximum value in 2015 appeared in April.

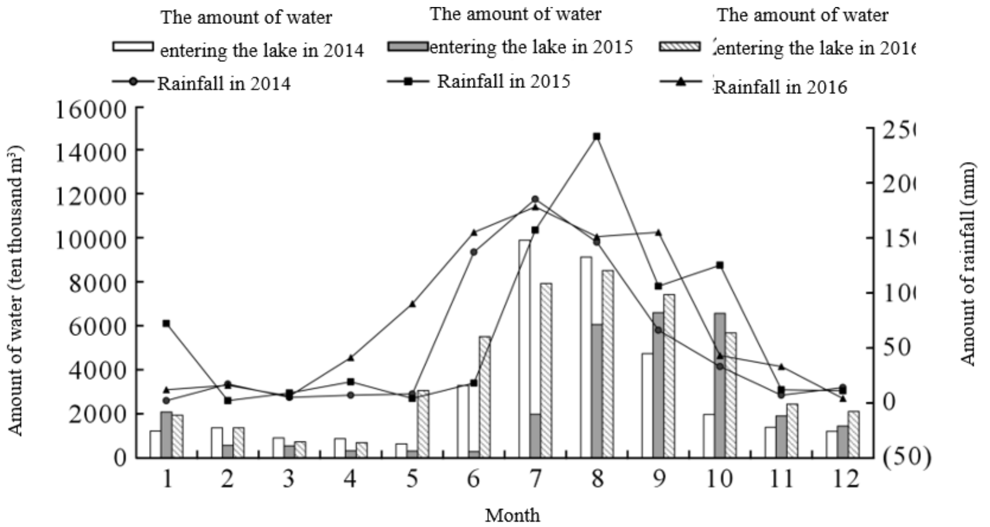


Figure 2. The monthly variation of water volume entering Erhai Lake of 27 tributaries and the rainfall.

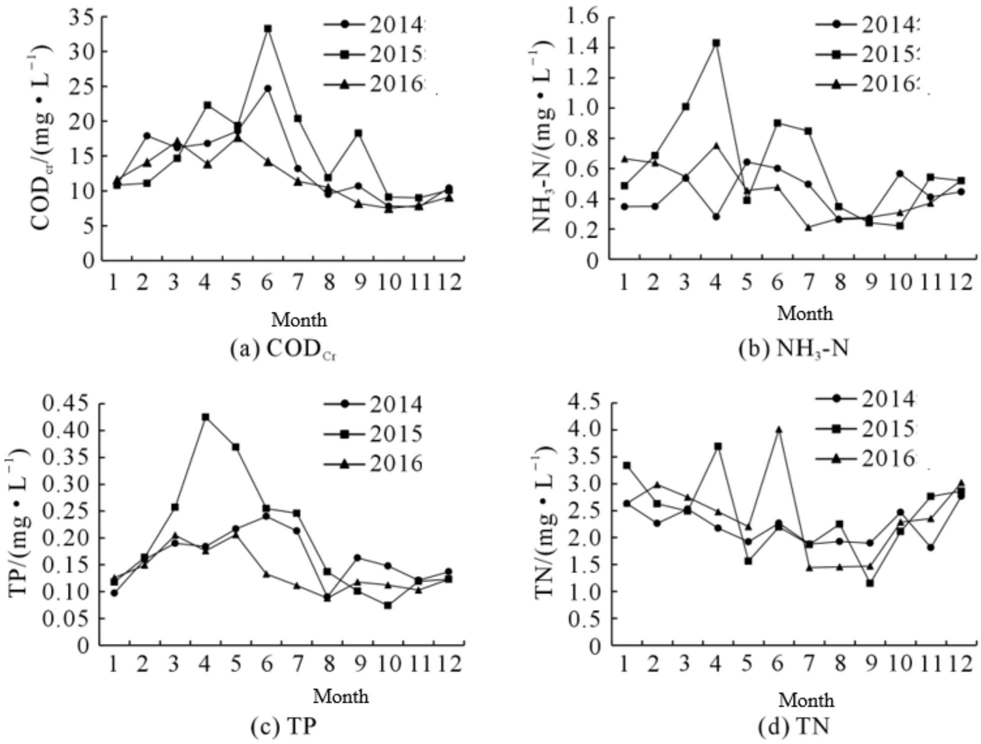
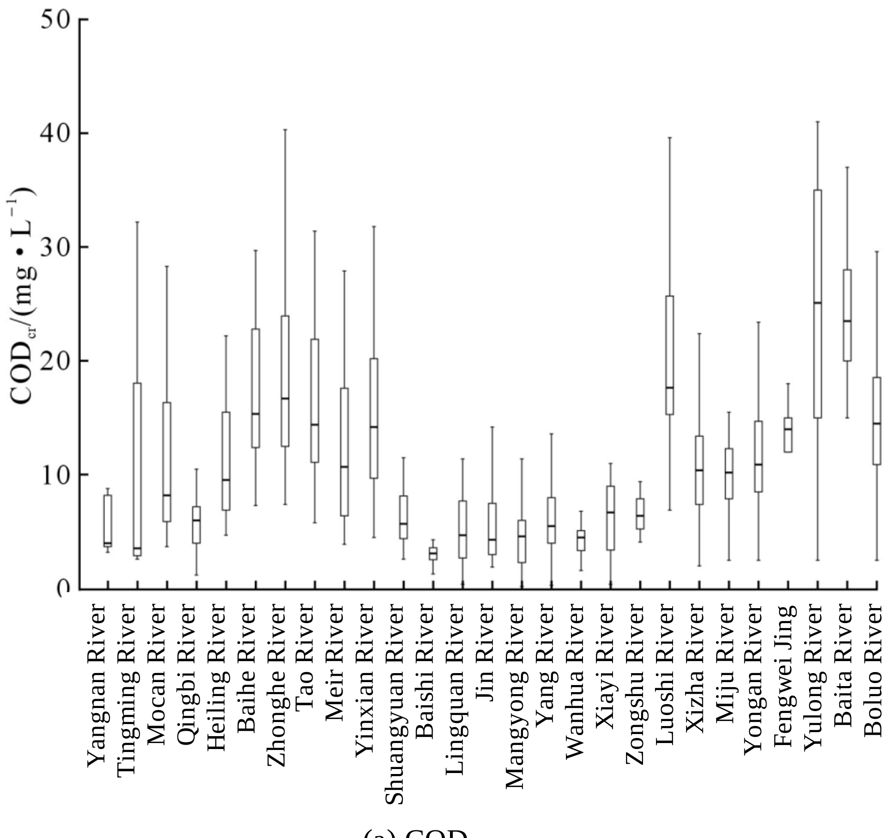
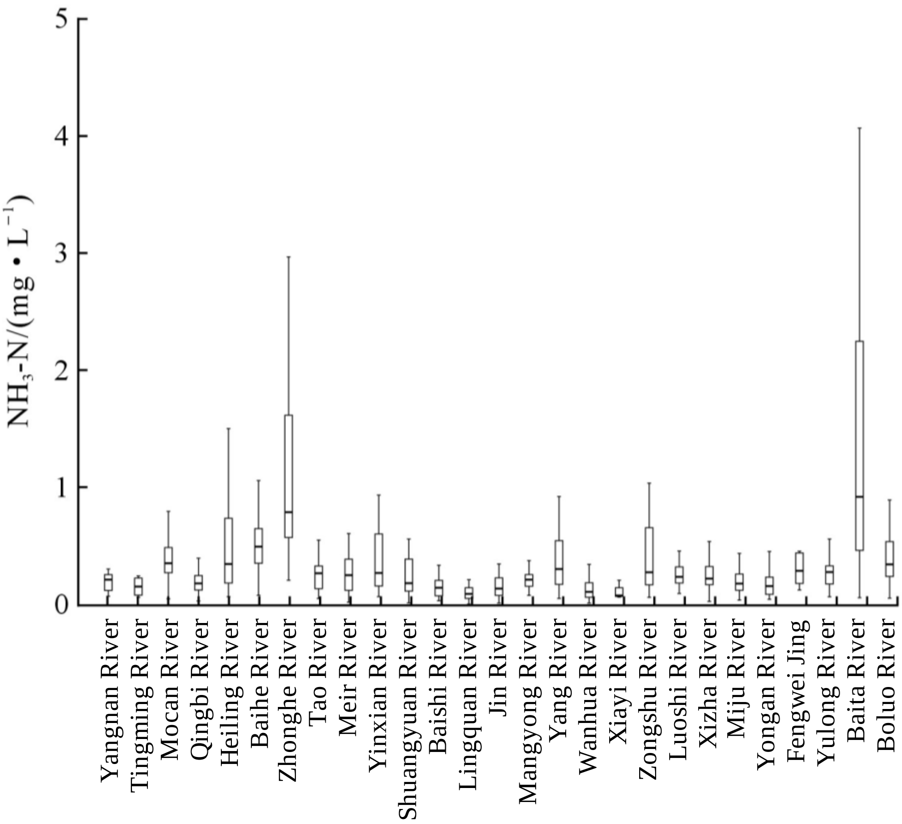


Figure 3. The monthly changes of pollutant concentration of the 27 main tributaries entering Erhai Lake.

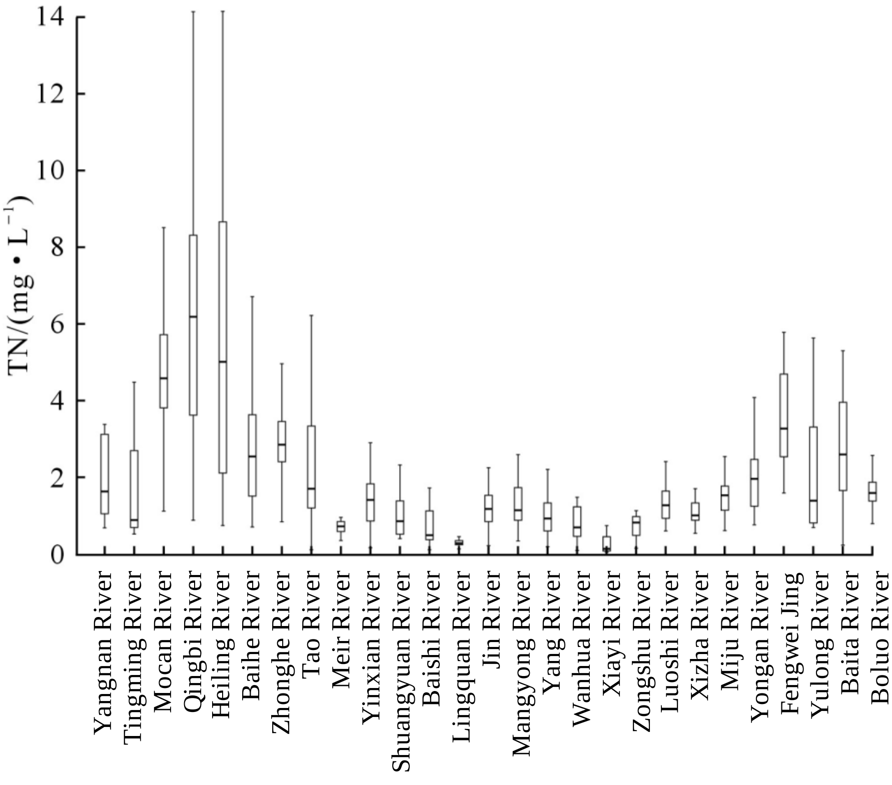
On the spatial scale, the overall pollutant concentration shows a "V" fluctuation trend of low in the north, South, high and middle (see **Figure 4**). The concentration of pollutants in the rivers in the south of the West Bank is high, especially in Wuxi (Mocan River, Qingbi River, Heilong River, Baihe River and Zhonghe River), whose sub watershed has a large population density and is a vegetable planting area; The concentration of rivers in the middle and north of the West Bank (Shuangyuanxi → Zongshu River) is low, and the population density of its sub watershed is small and basically farmland; the concentration of rivers on the north bank and Southeast Bank (Luoshi River → BOLUO River) increases, especially the concentration of chemical oxygen demand is at a high level. The population density of the "north three rivers" sub watershed is in the middle, and it is a garlic planting area (123,600 mu) and a cow breeding area (64,600 heads). The spatial difference of pollutant concentration is not as obvious as that on time scale.



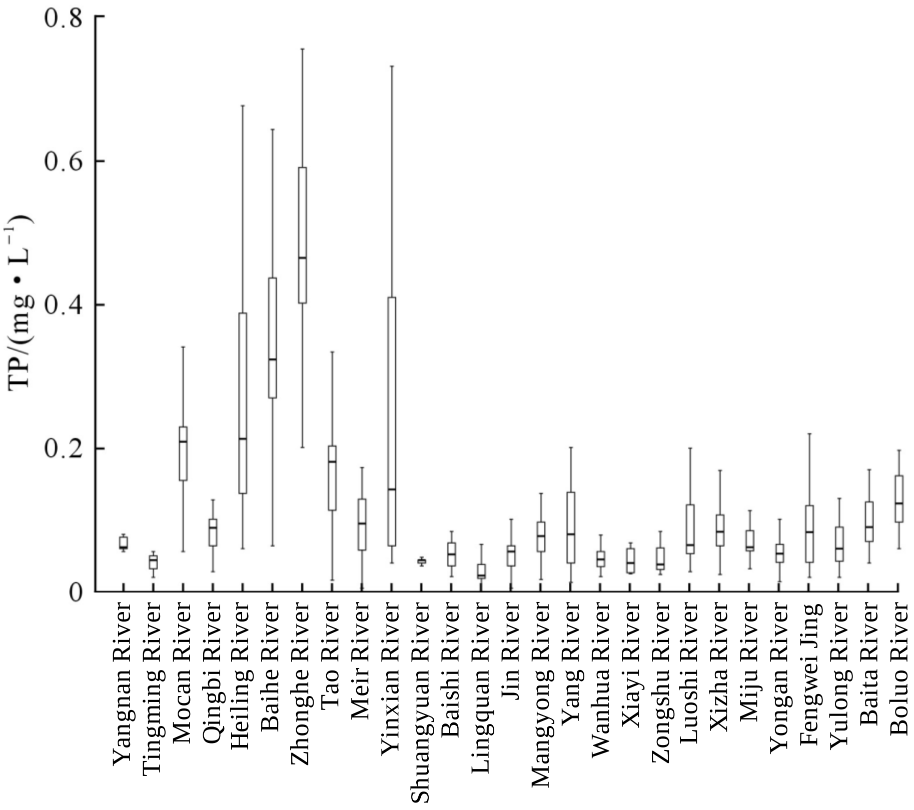
(a) COD_{Cr}


NH3-N/(mg • L−1)
5
4
3
2
1
0
Yangnan River
Tingming River
Mocan River
Qingbi River
Heiling River
Baihe River
Zhonghe River
Tao River
Meir River
Yinxian River
Shuangyuan River
Baishi River
Lingquan River
Jin River
Mangyong River
Yang River
Wanhua River
Xiayi River
Zongshu River
Luoshi River
Xizha River
Miju River
Yongan River
Fengwei Jing
Yulong River
Baita River
Boluo River

(b) NH_3-N


TN/(mg • L−1)
14
12
10
8
6
4
2
0
Yangnan River
Tingming River
Mocan River
Qingbi River
Heiling River
Baihe River
Zhonghe River
Tao River
Meir River
Yinxian River
Shuangyuan River
Baishi River
Lingquan River
Jin River
Mangyong River
Yang River
Wanhua River
Xiayi River
Zongshu River
Luoshi River
Xizha River
Miju River
Yongan River
Fengwei Jing
Yulong River
Baita River
Boluo River

(c) TN



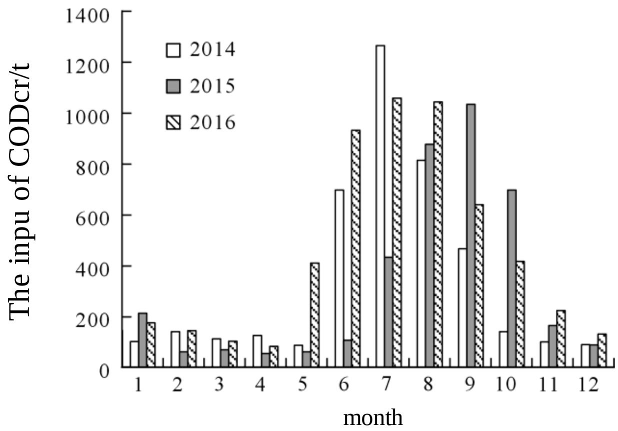
(d) TP

Figure 4. Spatial variation of pollutant concentration in the 27 main tributaries entering Erhai Lake

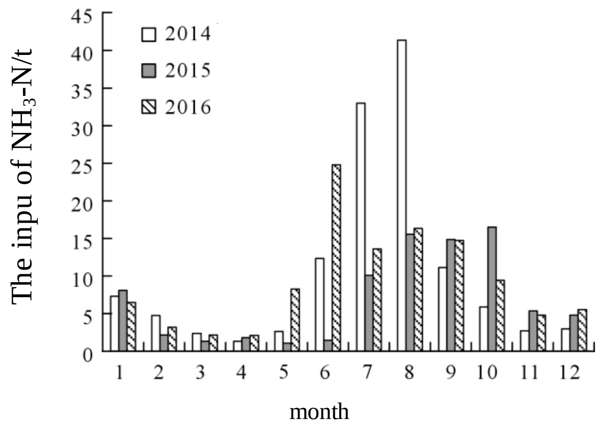
3.3. Load estimation of main rivers around Erhai Lake

The pollution load into the lake is determined by two factors: pollutant concentration and water volume. The pollution load into the lake of Erhai shows a trend of first decreasing, then increasing and then decreasing within the year (see **Figure 5**). The pollution load into the lake is mainly controlled by water volume [15,16]. From 2014 to 2016, the total nitrogen input of 27 rivers around Erhai Lake was 861.46 t, 525.07 t and 831.29 t, accounting for 52.5% of the total annual input in flood season95%, 60.45% and 49.92%; from 2014 to 2016, the total phosphorus input of 27 rivers around Erhai Lake was 58.97, 30.66 t and 51.76 t, flood season input accounts for 58.5% of the total annual input 89%, 67. 70% and 61.59%; from 2014 to 2016, the input of ammonia nitrogen in 27 rivers around Erhai Lake was 178.13, 96. 54 t and 130.81 t, accounting for 58.5% of the total annual input in flood season 36%, 60.77% and 53.25%; from 2014 to 2016, the chemical oxygen demand input of 27 rivers around Erhai Lake was 5681.02, 4195.69 t and 5857.73 t, and the input in flood season accounted for 59.56%, 75.11% and 62.74% of the total annual input.

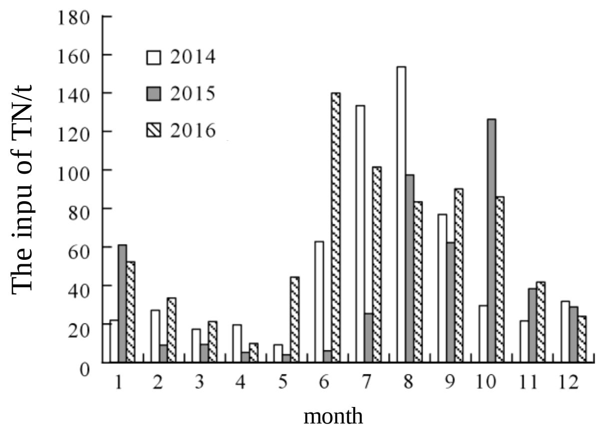
On the spatial scale, the water volume of 27 main rivers entering Erhai Lake is in the order of north bank > West Bank > east south bank. The contribution of pollution load is consistent with that of water volume, and their contribution rates are roughly the same (see **Table 1**). From 2014 to 2016, the water inflow of four rivers on the North Bank of Erhai Lake accounted for 55.5% of the total water inflow respectively 70%, 56.35% and 57.68%, and the proportion of total nitrogen input load is 64.3%, 60.0% and 58.9%, and the proportion of total phosphorus input load is 57.5% 7%, 59.1% and 61.4%, and the proportion of ammonia nitrogen input load is 72.5% 0%, 55.5% and 51.5% 3%, and the proportion of chemical oxygen demand input load is 75.5% 7%, 68.6% and 71.5%. "North three rivers" is the main input channel of pollutants in Erhai Lake area and the primary object of water pollution control and comprehensive restoration of rivers entering the lake. The pollution load of rivers entering the lake in the North mainly comes from agricultural non-point source pollution dominated by garlic and animal husbandry point source pollution dominated by dairy farming in the river sub basin.



(a) COD_{Cr}



(b) NH_3-N



(c) TN

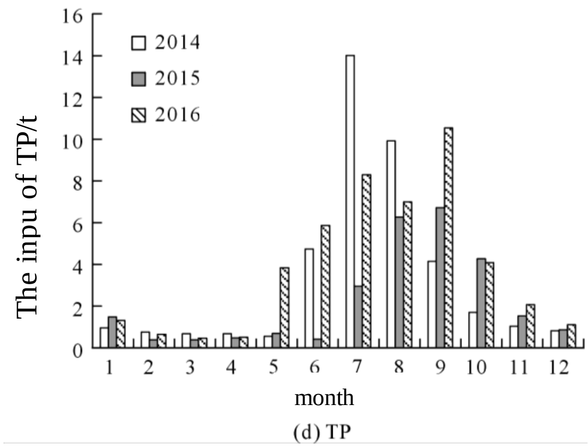


Figure 5. The monthly variation of pollution load of the 27 main tributaries entering Erhai Lake.

Table 1. Pollution load contribution rate of 27 main tributaries entering Erhai Lake %.

Rivers entering the lake	2014				2015				2016			
	COD_{Cr}	NH_3-N	TP	TN	COD_{Cr}	NH_3-N	TP	TN	COD_{Cr}	NH_3-N	TP	TN
Article 19 of the West Bank	17.1	21.5	38.9	31.5	18.5	24.4	31.6	30.7	15.4	28.6	28.4	31.8
4 on the north bank	75.7	72.0	57.7	64.3	68.6	55.5	59.1	60.0	71.5	51.3	61.4	58.9
4 on the southeast bank	7.2	6.5	3.4	4.2	12.9	20.1	9.3	9.3	13.1	20.1	10.2	9.3

4. Discussion

It is found that the pollutant concentration of 27 main rivers entering Erhai Lake is closely related to the rainfall of the basin. Pearson correlation analysis is carried out on the pollutant concentration and the corresponding rainfall, and the results are listed in **Table 2.** The concentrations of total nitrogen and ammonia nitrogen in rivers entering the lake have a very significant negative correlation with rainfall ($P < 0.01$), and the correlation coefficients are 0.338 and 0.330, indicating that the concentrations of total nitrogen and ammonia nitrogen are greatly affected by rainfall; the concentrations of total phosphorus and chemical oxygen demand are significantly negatively correlated with rainfall ($P < 0.05$), and the correlation coefficients are 0.213 and 0.162. The concentration of total phosphorus and chemical oxygen demand are less affected by rainfall [17].

Table 2. Pearson(bilateral) correlation analysis of pollutant concentration and rainfall of the 27 tributaries entering Erhai Lake.

Pollutant concentration (n = 36)	Rainfall	
	r value	P value
TN	−0.338	<0.01
NH_3-N	−0.330	<0.01
TP	−0.213	<0.05
COD_{cr}	−0.162	<0.05

The target of Erhai seawater functional area is class II water body; Erhai Lake was a class II water body for seven months in 2014, and the annual average water quality was class II; in 2015 and 2016, Erhai Lake was classified as class II water body for 6 months and 5 months respectively, and the annual water quality was classified as class III. From 2014 to 2016, there was no large-scale cyanobacteria bloom, the water body remained at the mesotrophic level, and nitrogen and phosphorus became the main contributing factors to the eutrophication of Erhai lake the relationship between the pollution load of 27 main rivers entering Erhai Lake and the water quality index and algal biomass of Erhai Lake area is further studied, trying to find out which nutrients can significantly increase the algal biomass when the water body is in the mesotrophic state, and to evaluate the impact of the direct pollution load of rivers entering the lake on the water quality of the lake area. Through the normal distribution test and correlation analysis between the monthly mean concentrations of total nitrogen, total phosphorus, chemical oxygen demand and chlorophyll a in the lake area and the pollution load of main rivers entering the lake in the same period (see **Table 3**), it is found that there is a very significant positive correlation between the total nitrogen input of rivers entering the lake and the total nitrogen concentration in the lake area, the total phosphorus input and the total phosphorus concentration in the lake area ($P < 0.01$), and the correlation coefficients are 0.565 and 0.477, it shows that the input of total nitrogen and total phosphorus from the rivers entering the lake directly affects the concentration of total nitrogen and total phosphorus in the lake area, and is an important source of nitrogen and phosphorus in Erhai Lake. There is no significant correlation between the input of ammonia nitrogen and the concentration of ammonia nitrogen in the lake area, and the input of chemical oxygen demand and the concentration of chemical oxygen demand in the lake area, indicating that the input of ammonia nitrogen and chemical oxygen demand in the river has little impact on the concentration of ammonia nitrogen and chemical oxygen demand in the lake area the concentration of chlorophyll a in the lake area is not significantly correlated with the load input of total nitrogen, total phosphorus, ammonia nitrogen and chemical oxygen demand in the river entering the lake, but the correlation coefficient is positive, indicating that the input of nitrogen, phosphorus and organic pollutants may increase the biomass of Erhai algae.

Table 3. Pearson (bilateral) correlation analysis between the pollution load of the 27 tributaries entering the lake and the water quality parameter in the lake area.

Lake load (*n* = 36)	**Water quality index of Lake area**				
	ρ_{TN}	ρ_{TP}	$\rho_{COD_{Cr}}$	$\rho_{NH_3\text{-}N}$	$\rho_{chl\text{-}a}$
TN	0.565**	0.622**	0.350*	0.036	0.234
TP	0.524**	0.477**	0.192	0.174	0.132
COD_{Cr}	0.624**	0.553**	0.188	0.176	0.286
NH_3-N	0.672**	0.592**	0.314	0.129	0.220

Note: * indicates significant correlation, $P < 0.05$; * indicates a very significant correlation, $P < 0.01$.

5. Conclusions and suggestions

(1) From 2014 to 2016, the total water inflow of 27 major rivers into the lake was 366 million m^3, 287 million m^3 and 474 million m^3 respectively. The water inflow in flood season accounted for 79.17%, 74.90% and 61.96% of the water inflow in the whole year respectively. The water inflow into the lake was positively correlated with the precipitation in the basin.

(2) On the time scale, the pollutant concentration showed a fluctuating trend of first increasing and then decreasing in the whole year; on the spatial scale, the overall pollutant concentration shows a "V" fluctuation trend of low in North, South, middle and high schools.

(3) The pollution load of Erhai Lake decreases first, then increases and then decreases in the year. The load of Erhai Lake is mainly controlled by water volume, and the contribution rate of pollution load is in the order of north bank > West Bank > southeast bank.

(4) The pollutant concentration of the main rivers entering Erhai Lake has a significant negative correlation with the rainfall in the basin. The total nitrogen input of the rivers entering Erhai Lake has a very significant positive correlation with the total nitrogen concentration in the lake area, and the total phosphorus input has a very significant positive correlation with the total phosphorus concentration in the lake area. It is an important source of nitrogen and phosphorus in Erhai Lake.

According to the analysis of the monitoring results of the main rivers entering Erhai Lake, the water environmental problems of the rivers entering Erhai Lake are mainly as follows: in the dry season, the river water body is seriously polluted and the water volume is seriously insufficient, half of the rivers are cut off, the pollutant concentration law is lower in the wet season than in the dry season, the flow is small and the evaporation is large in the dry season, and the concentration rises rapidly, the impact pollution load brought by the initial rainwater and the nutrients in the farmland retreat cause the high concentration in the early rainy season; the limiting factors of the water quality category of rivers entering the lake are total nitrogen and total phosphorus, the population density along the coast is large, the land use is mainly vegetable fields and paddy fields, and the agricultural non-point source pollution is prominent; river ecological degradation, low vegetation coverage, narrow buffer zone, hard embankment on both sides, and fragile riverside function Combined with the current situation of land use along the river and adhering to the principle of coordination and unity of water quantity, water quality and water ecology, the following suggestions are put forward.

(1) Regulate water volume. The annual water volume of Erhai Lake inflow river is more in rainy season and less in dry season, and the polarization is serious. It is recommended to take reasonable engineering measures in the upstream of the river channel to control the water volume into the lake in wet season, so as to achieve water replenishment in dry season.

(2) Improve water quality. The river pollution load mainly comes from agricultural non-point sources. It is necessary to adjust the planting structure along the coast, apply fertilizer scientifically and reasonably, and strictly control the return water of farmland.

(3) Restore water ecology. Appropriate river ecological restoration technology shall be selected for each river, and "one river, one policy" shall be repaired according to local conditions.

Conflict of interest: The author declares no conflict of interest.

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