Temporal and spatial variation analysis on nutritive salt of Hongze Lake

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ABSTRACT

This paper mainly focuses on the research of the monitoring data about the total nitrogen (TN), total phosphorus (TP) of ten monitoring points of Hongze Lake in 28 years. Our study adopts the technical methods such as difference comparison, correlation analysis, Mann-Kendall, etc. to analyze the statistical characteristics, regional differences, and temporal and spatial variation condition of ten monitoring points of Hongze Lake in 1986-2013 as well as the reason for the time and space variation of TN and TP. The results show that the TN and TP of Hongze Lake change dramatically during the period of 1994-2004. In all the monitoring periods, TN and TP of the HZ5, HZ6, HZ7, HZ8 monitoring points in the estuary surrounding the Huaihe River are the highest, which suggests that TN and TP of Hongze Lake should not be ignored for the pollution along the Huaihe River. The TN concentration in the core area is the highest, but that in the development control area is the lowest. In most of the years, TN concentration is higher than 2 mg/L, and the water quality is V class and poor V class water quality in China's Environmental Quality Standards for Surface Water (GB3838-2002). TP concentration of the three areas is basically close, that is lower than 2 mg/L in most of the years, and the water quality is within the V class. The TN and TP concentration of Hongze Lake decreased and intensifying trend of eutrophication is controlled after 2004.

Keywords: Hongze Lake, TN, TP, Temporal and spatial variation

1. Introduction

Hongze Lake is the fourth largest freshwater lake in China. It is located in the midwest region of Jiangsu Province and the middle reaches of the Huaihe River with an area of 1,959 km^2 (water level of 1.25 m). The average water depth is 1.9 m, the deepest one is 4.5 m, and the volume is 30.4×10^8 m^3. It can receive the Huaihe River in the west, empty into the Changjiang River in the south, lead to the Yellow Sea in the east, connect the Yishu in the north, and regulate and store the 158,000 km^2 water of Huaihe upper and middle reaches. It is the largest plain shallow lake with comprehensive utilization function such as flood control, irrigation, water diversion, aquaculture, water transport, hydroelectricity, and so on in our country [1-4].

In recent years, because of the evolution of the natural environment, environmental pollution and unreasonable development activities of human, etc., the environment of Hongze Lake water is polluted in different levels. The Hongze Lake area shrinks dramatically, water quality deteriorates, the wetland function decreases, and the ecological environment presents degradation trend. These severely restrict the sustainable utilization of Hongze Lake water resource and sustainable development of economic society, especially, have an important influence on the implementation and operation of the east route of the south-to-north water diversion project [5-8]. This is not only related to water quality of the south-north water diversion project, clean water corridor, and the success or failure of the construction of the ecological corridor, but also directly restricts sustainable development of society and economy in the water shortage region of the north of our country. It is of great significance to know the Hongze Lake wetland ecosystem characteristics and that of the environmental problems, protect and build Hongze Lake wetland ecosystem, strengthen the consciousness to protect the Hongze Lake wetland, and promote the sustainable development of regional economy and biodiversity protection in China. TN and TP are the most serious pollutants of the Hongze Lake in the environmental pollutants. The content of the TN and TP is crucial for the water environment quality of Hongze Lake and the growth of algae. Hence, the key problems that must be resolved for effectively preventing Hongze Lake pollution are to know the TN and

TP statistics characteristic, analyze their time-space change law, and parse their pollution source. Our country's researchers have carried out the related study on this, for example, Zhang et al. [9] analyzed the vertical distribution characteristics of the TN, TP and heavy metal in the Hongze Lake deposits. Li et al. [1] analyzed the water quality change trend of the Hongze Lake for nearly 30 years, studied seasons and the interannual change law, and stated the overall trend of the water quality change in the Huai River basin.

The author are based on the precious studies and TN and TP monitoring data of Hongze Lake for the continuous 28 years from 1986 to 2013, combines the wind power and flow velocity, through all kinds of the data mining methods, to analyze TN and TP statistics characteristics and the time-space and season change situation, and analyze the reasons for this change in detail. Those are expected to provide references for correctly formulating Hongze Lake environment protect plan and proposing the scientific environmental control technology plan of Hongze Lake water.

2. Materials and Methods

2.1. The Study Regions Profile

Selecting sample points need consider the situations such as the shape of Hongze Lake, terrain, landform, lake aquaculture, and the rivers into and out of the lake. A total of ten sampling points (shown in Fig. 1 and Table 1) basically cover all the typical waters.

Table 1. Hongze Lake Sampling Points of the Corresponding Region

Sampling points	Corresponding region
HZ1	Gaoliangjian floodgate and Erhe floodgate
HZ2	Sand basin
HZ3	Chengzi Lake centre
HZ4	Chengzi Lake open water
HZ5	Hongze Lake central open water
HZ6	Huaihe River by Laozishan into Hongze Lake
HZ7	Hongze Lake west central open water
HZ8	Laosui River estuary
HZ9	Huaihongxin River, Xinbian River and Xinsui Rive estuary
HZ10	Sanhe floodgate

The research point is No. HZ1-10, and the sampling frequency is once a month. The whole lake is investigated in autumn (November) and summer (June) every year.

2.2. Collection and Analysis for Water Samples

The water sample was taken in the middle of each month of each year in 1986-2013, and TN and TP were measured, meanwhile, hydrological information such as wind speed, flow velocity, and so on. Due to the difference of the lake region situation in individual years, the sampling time was slightly earlier or later, but the overall time changed little. The water sampling method is in accordance with that of the literature [10] which used comprehensive water
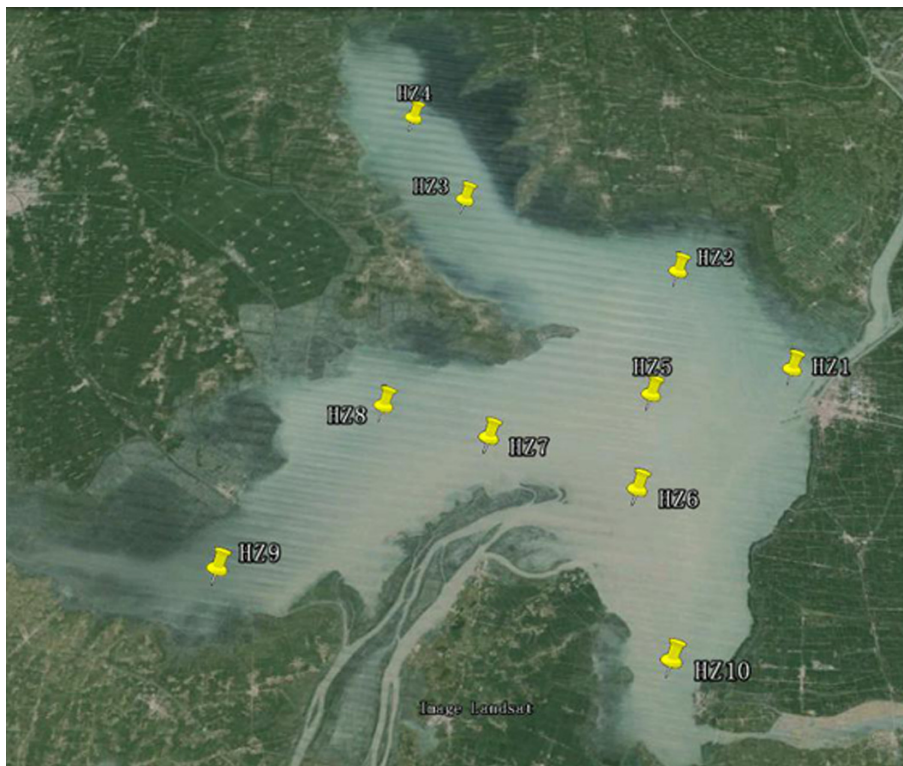
Fig. 1. Hongze Lake sampling points distribution.

samples method and the sampling depth is the surface water (0.1-1.0 m). After water sampling, the sample was filtered by the 0.45 μm microporous membrane, kept in the refrigerator of −20°C, and brought back to the lab to finish the analysis within the stipulated time. Total nitrogen and total phosphorus were analyzed by the alkaline potassium persulfate digestion ultraviolet spectrophotometric method (GB/T11894-1989) and ammonium molybdate spectrophotometric method (GB/T11893-1989), respectively. The data analysis and quality control of the laboratory was in accordance with the requirements of the literature [11].

3. Results and Discussion

3.1. TN and TP Interannual Difference Comparision of Hongze Lake

The average values TN and TP of ten monitoring points of Hongze Lake in 28 years are shown in Figs. 2 and 3.

Fig. 2 shows that the average value of the TN concentration in three monitoring points of HZ3, HZ4, HZ9 is 1.33, 1.37 and 1.65mg/L, respectively, which are the lowest monitoring points over the years. HZ3 and HZ4 are the open waters of Chengzi Lake. HZ9 is the Lihe River depression waters where the Huaihongxin River, Xinbian River, and Xinhuai River flow. At present,
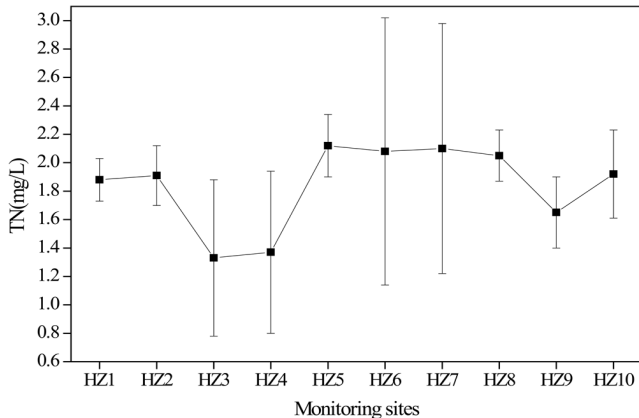

Fig. 2. 1986-2013 year different monitoring points TN average values.
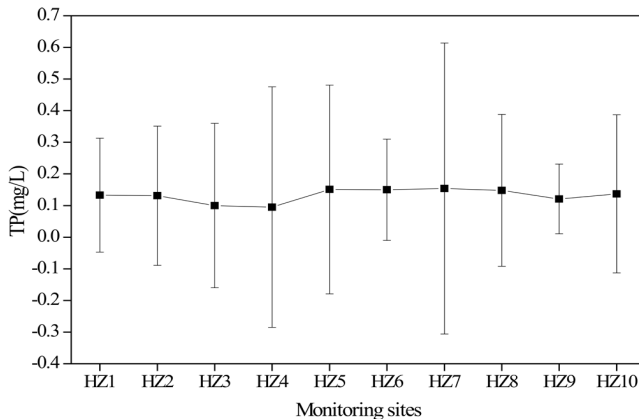

Fig. 3. 1986-2013 year different monitoring points TP average values.

here is the only place that there is large area of the natural aquatic plants. The concentration of TN is lower because of the influence of the aquatic vegetation on the water quality. However, there is no river from outside flowing into HZ3 and HZ4. They are less affected by the outside, their natural state is in good condition, and TN concentration is also lower. In Fig. 2, the TN concentration of four monitoring points of HZ5, HZ6, HZ7, HZ8 is the highest, of which the TN concentration of monitoring point HZ5 is the highest about 2.12 mg/L that is higher than the V class water quality (2.0 mg/L) in China's Environmental Quality Standards for Surface Water (GB3838-2002) delonging to the poor V class. The four points are laid around the Huaihe River estuary. It is thus clear that the TN concentration of Hongze Lake is mainly attributed to the Huai River. The Huai River estuary near Hongze Lake is also the important 'pollutant area'. Hence, this region should be the governance emphasis in governing Hongze Lake eutrophication. It should be further controlled that the waste water of Huai River along the coast is directly discharged into the Huai River. The prevention and control of the land-based pollution should be strengthened and the amount of nitrogen into the lake should be further reduced. The TP change law in Fig. 3 is similar to that in the Fig. 2. The highest point HZ7 of TP concentration is 0.154 mg/L, which is higher than IV class water quality (0.1 mg/L) of the China's Environmental Quality Standards for Surface Water (GB3838-2002) and lower than the V class water quality (0.2 mg/L), namely, the water quality is between the two.

3.2. TN Spatial Change Analysis of Hongze Lake

3.2.1. TN time change trend of Hongze Lake
Mann-Kendall method is used to study the time changing trend of TN in Hongze Lake. In Mann-Kendall method, the sample need not obey a certain distribution, and will not be disturbed by minority outlier. This method is more suitable for a type and an order variable, its calculation is easier, and is a non-parameter method. The basic principle of this method is that n samples (TN, TP) and the monitoring time sequence x (TN, TP) for 28 years (the annual average) are used to structure the sequence as follows.

$$S_k = \sum_{i=1}^{k} r_i$$

$$r_i = \begin{cases} +1 & when \ x_i > x_j \\ 0 & other \end{cases} (j=1, \ 2, \ ..., \ i) \quad (1)$$

where i is the different monitoring periods of TN, the sequence S_k is the cumulative number that the data number of ith period (TN) is greater than that of jth period (TN). Under random independent assumptions of time sequence, the statistics is defined as:

$$UF_k = [s_k - E(s_k)] / \sqrt{Var(s_k)}$$
$$(k=1, \ 2, \ ..., \ n) \quad (2)$$

In the equation, $UF_1 = 0$, $E(s_k)$ and $Var(s_k)$ is the average value and variance of the cumulative number s_k, respectively. When x_1, x_2, x_n are independent of each other as well as the same continuous distribution, they are calculated by the Eqs. (3), (4), respectively.

$$E(S_k) = n(n+1)/4 \quad (3)$$

$$Var(S_k) = n(n-1)(2n+5)/72 \qquad (4)$$

UF_k is the standard normal distribution. It is the statistics sequence calculated by the time sequence x. The significant level is given as $U_a(0.01)=2.62$ (TP is 2.65). If $|UF_k|>2.62$ (TP is 2.65), the sequence has the obvious change trend. According to reverse order x_n, x_{n-1}, x_1 of the time sequence x, the above process is calculated repeatedly. Meanwhile, let $UB_k=-UF_k$, UB_k is the anti-sequence of UF_k [12-14].

The graph of the UF_k and UB_k is drawn, respectively. If UF_k or UB_k is bigger than 0, the sequence is on the rise. If UF_k or UB_k is smaller than 0, the sequence is on the decline. When they exceed the critical values, the rising and falling trend of the sequence is outstanding. If UF_k and UB_k interact within the boundary (shown in Fig. 4), the point of intersection is the start time for abrupt change. The results that the Mann-Kendall method studies TN time change trend are shown in Fig. 4 where UB_k is the anti-sequence of UF_k.

Fig. 4 illustrates that TN concentration of Hongze Lake in almost 28 years fluctuates greatly during the period of 1994-2004. After 2004, the fluctuation levels off. In 1994, the UF obtained by the TN calculation of Hongze Lake reaches the critical value 2.62 and presents significant level, which indicates that the nitrogen pollution prevention of Hongze Lake has reached a critical period. That should take measures to curb pollution acceleration and aggravation trend as soon as possible. But until 2004, the TN fluctuation of Hongze Lake has still been great. That is because Hongze Lake occurred six wide range of water pollution incidents, and one of them caused the loss of 150 million yuan in 1994 [15]. It is the biggest loss in the successive water pollution incidents. From the Mann-Kendall analysis results, the fluctuation of TN is great in 1994-2004, which is directly related to the several major water pollution incidents.
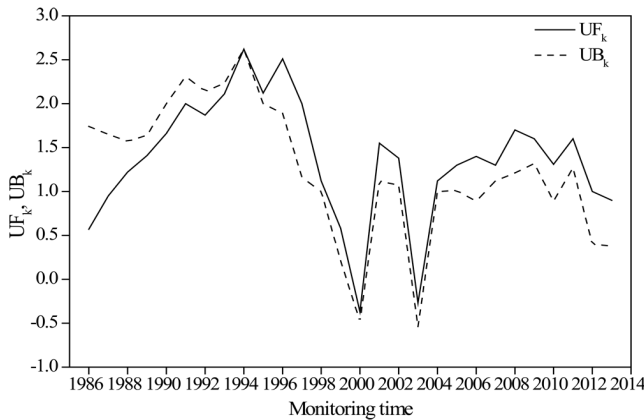

Fig. 4. 1986-2013 year Hongze Lake TN change trend Mann-Kendall analysis result.

3.2.2. TN spatial change trend of Hongze Lake

On the basis of lake region function, the HZ4, HZ7, HZ8, HZ9, HZ10 are classified into the core region, the HZ1, HZ3, HZ5, HZ6 are classified into the buffer region, and the HZ2 is classified into the development control region. The calculating results of

TN average in each region from 1986 to 2013 are shown in Fig. 5.

Fig. 5 illustrates that the TN concentration of the core lake region is higher than that of the buffer region and the development control region. The TN concentration in development control region is the lowest. In general, the concentration of three regions is all in the downward trend. But TN concentration in core region decreases slowly, the average value of TN is more than 2 mg/L in most of the years. According to the single factor evaluation method, the water quality of the lake region is classified into the poor V class, and the pollution control foreground is not optimistic. This should increase further control for nitrogen pollutants into the lake. The TN concentration of development control region is lower, which suggests that this region is less affected by the outside, should be developed moderately, and should be paid equal attention to exploitation and protection. The aggravated pollution of this region should be controlled.
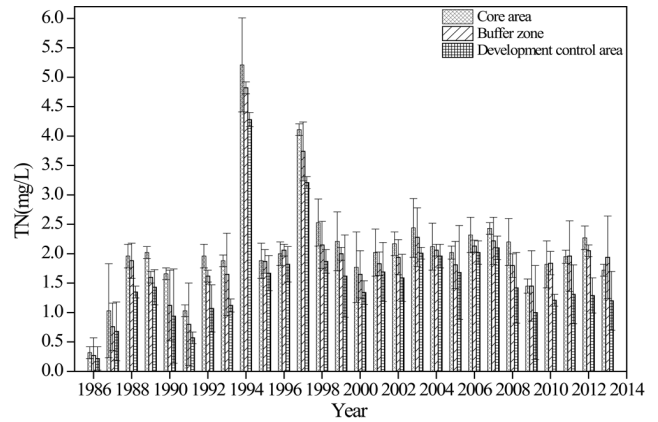

Fig. 5. 1986 -2013 year Hongze Lake different region TN average value change.

3.3. TP Spatial Change Analysis of Hongze Lake

3.3.1. TP time change trend of Hongze Lake

Mann-Kendall method is also used to study the TP time change trend of Hongze Lake. The results are shown in Fig. 6, where UB_k is the anti-sequence of UF_k.
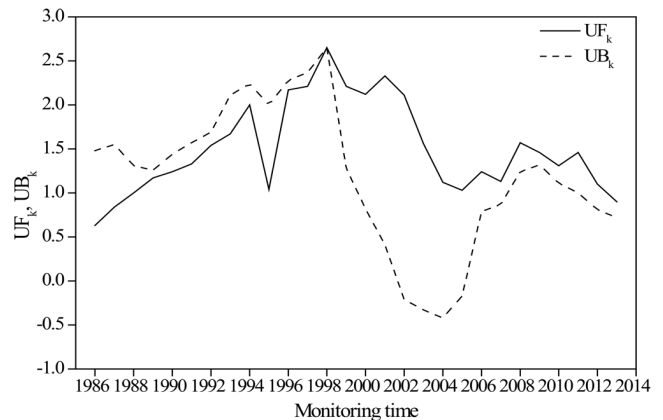

Fig. 6. 1986-2013 year Hongze Lake TP change trend Mann-Kendall analysis result.

Fig. 6 illustrates that the TP concentration of Hongze Lake in almost 28 years fluctuates greatly during the period of 1994-2004. After 2004, the fluctuation levels off. In 1998, the UF obtained by the TP calculation of Hongze Lake reaches the critical value 2.65 and presents significant level, which indicates that the phosphorus pollution prevention of Hongze Lake has reached a critical period. That should take measures to curb pollution acceleration and aggravation trend as soon as possible. The fluctuation of TP is great in 1994-2004, which is directly related to the six major water pollution incidents [15].

3.3.2. TP spatial change trend of Hongze Lake
According to the 3.2.2, the monitoring points are divided, and the regional average (TP) is calculated in 1986-2013, shown in Fig. 7. Fig. 7 shows that the TP concentration of core, buffer and development control areas is close to each other except for the abnormal situation in 1995 and 2007, and TP values are less than 0.2 mg/L in most of the years. According to the P single factor evaluation, the water quality of the lake is within the V class, which suggests that the eutrophication is still in the controllable range. But the TP concentration is higher than 0.1 mg/L in most of the years, hence, there exists the potential danger of serious eutrophication and blue algae outbreak. That should strictly control the total phosphorus pollutants into the lake to avoid aggravated eutrophication.
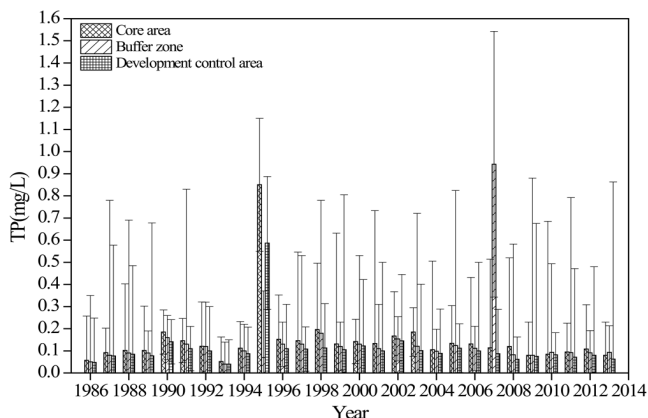

Fig. 7. 1986 -2013 year Hongze Lake different region TP average value Change.

4. Conclusions

a. TN monitoring data statistics of Hongze Lake in 28 years shows that TN concentration value of the four points HZ5, HZ6, HZ7, HZ8 near the estuary surrounding the Huaihe River is the highest, but the TN concentration of the HZ3, HZ4 and HZ9 lake region away from the estuary is the lowest. Hence, it is clear that nitrogen pollution of Hongze Lake is affected by breed aquatics, land-based pollution, and external factors such as social and economic development, etc. more seriously. The change of TP is similar to that of TN.

b. During the period of 1994-2004, the water quality of Hongze Lake changed dramatically, TN and TP changed slowly, and the

water quality was stable after 2004. Using TN to evaluate the lake water quality, TN concentration is higher than 2 mg/L in most of the years, and the water quality is the V class or poor V class. Using TP to evaluate the lake water quality, TN concentration is lower than 0.2 mg/L in most of the years, and the water quality is within the V class. The eutrophication degree of Hongze Lake is still in the controllable range.

c. The TN concentration in different lake areas from high to low is core, buffer and development control area in almost 28 years, but the TP concentration of three areas is basically flat with a smaller concentration difference.

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