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The Correlations of Algae Density Distribution with Water Quality and Wind Effect in the Hongze Lake

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Abstract: In order to investigate the correlations of algae density distribution with water quality and wind effect in the Hongze Lake, point sampling was conducted all over the lake area in 2013 to collect data of water quality and algae density. Then, combined with data of wind scale and direction, the partial correlation method was used to analyze the correlations of algae density distribution with water quality and wind effect. The results suggest that: the algae density in spring and summer is 12.3×10^5ind./L and 32.9×10^5ind./L respectively; the algae density in spring is lower than that in summer; and the density in the northern part is higher than that in other regions. The concentrations of TN and TP are 2.23mg/L and 2.35mg/L in spring, and 0.1mg/L and 0.187mg/L in summer. The concentrations of TN and TP are higher in summer than in spring. Meanwhile, the concentrations of TN and TP around the inlet of the Huaihe River are higher than those in other sampling points. The partial correlation analysis results suggest that: the algae density in spring is not correlated with TN, TP or wind scale, while the density in summer is positively correlated with the concentration of TN. TN is still the limiting factor for algae outbreak in the Hongze Lake in summer. It should also be noted that the Hongze Lake has not developed to the serious eutrophication state. The inlet/outlet rivers and the lake current pattern are important factors that influence the algae density distribution in the Hongze Lake.

Keywords: *Hongze Lake; algal density; water quality; wind function; temporal and spatial distribution*

1. Introduction

The Hongze Lake is located in the middle west of Jiangsu Province and the middle reaches of the Huaihe River. It is the fourth largest freshwater lake in China, occupying a total area of 2096km^2 (when water level is at 12.5m), with an average depth of 1.9m, a maximum depth of 4.5m and a total volume of 31.27×10^8m^3. Geographically, the Hongze Lake absorbs water from the Huaihe River on the west and releases water to the Yangtze River on the south; it also connects to the Yellow Sea on the east and the Yishu River on the north. Functionally, it regulates the water supply of the upper and middle reaches of the Huaihe River, occupying a total area of 158,000 km^2, making it China's largest plain shallow lake with comprehensive functions of flood control, irrigation, water diversion, aquatic production, water transportation and hydropower utilization [1-4]. Large areas of marsh land, bottom land and low-altitude plain wetland are distributed in the surrounding areas of the lake. The wetland ecosystem of the entire lake region is completely developed.

Water quality monitoring data shows that the water quality of the Hongze Lake has reached the moderate eutrophication state, with organic matters, ammonia, phenol and total mercury as the main pollutants. With the worsening of the eutrophication process, the algae density of the Hongze Lake has been growing continuously in recent years and shown the trend of bloom outbreak. Algae density (the number of algae cells in unit volume) is the most direct indicator for the amount of algae cells and the intensity of potential bloom outbreak. Algae in the algae accumulation area is mainly composed of local growing algae and algae drifting from other areas. The former type is growing within the lake area, the density of which is primarily influenced by regional water quality and climate. The latter type comes from other areas, the density of which is primarily influenced by wind scale, wind direction and other weather conditions [5]. Therefore, it is necessary to take into account the water quality, wind scale, wind direction and other factors comprehensively in order to reach objective analysis results.

The research methods for algae density and its influencing factors vary greatly depending on research objectives. The method of correlation analysis can be applied to study algae density or the simple relationship between ρ(Chla) and water quality [6]; the method of canonical correspondence analysis can be applied to study the correlation between algae density distribution of different algae types and main water quality factors [7]; the method of lagged correlation analysis can be applied to study the correlations of algae density distribution with wind scale and wind direction [8]. To investigate the impact of multiple variables on algae density distribution, the methods of multiple linear stepwise regression and partial correlation analysis can be considered. The former method aims to establish a multiple regression equation between dependent variables (algae density) and independent variables (the water quality factor and meteorological factors), in order to determine the main factors by stepwise regression. The latter method aims to fix the dependent variable and one of the independent variables and control the linear effects of other variables, in order to analyze the linear correlation between these 2 variables; it reflects the essential correlation between the target objects [9]. The multiple linear stepwise regression method is featured with the advantage of prediction model, but for data analysis based on a large number of investigations at the same time, in order to achieve the fitting of the whole model, it may be necessary to abandon factors that are closely associated with the dependent variable. In view of this problem, the present study applied the partial correlation analysis method to investigate the impact of the water quality factor and wind effect on algae density distribution in the Hongze Lake, in order to provide technical support for the research of the key factors that influence the algae density distribution in the Hongze Lake.

2. Materials and methods:

2.1. Sample collection and detection:

A total of 10 sampling points are selected taking into account the shape of lake, topographic features, the aquaculture status, as well as the conditions of inlet/outlet rivers (Figure 1 and Table 1). The sampling method references to the synthetic water sampling method described in Literature [10]. For water bodies with even mixture and depth ≤2m, the sampling depth is near the lake surface (0.1-0.5m). For water bodies with depth >2m, samples are collected from surface, middle layer and bottom layer respectively and then mixed together. Mix 500 mL lake water with 5 mL compound iodine solution, and bring the sample back to the laboratory under refrigerated condition. All samples are investigated and counted using a 10x40 microscope. Take another water sample and filter it with 0.45μm micro-porous film; keep the sample in refrigerator at the temperature of -20℃. Bring the sample back to laboratory to detect its total nitrogen (TN) and total phosphorus (TP). TN and TP are analyzed by the alkaline potassium persulfate digestion UV spectrophotometric method (GB/T11894-1989) and the ammonium molybdate spectrophotometric method (GB/T11893-1989) respectively. The sampling frequency is once per month.

2.2. Processing of wind scale and wind direction data

Data of wind speed and wind direction is extracted from the historical data of meteorological stations near the sampling points of the Hongze Lake.

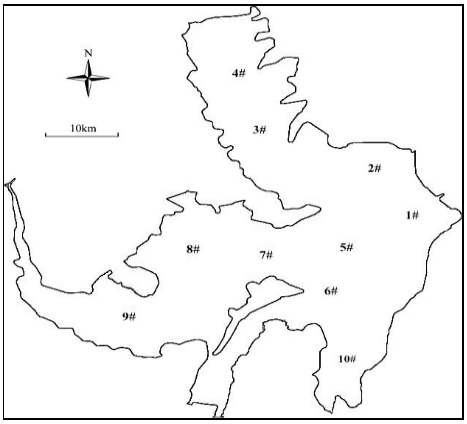


Figure 1: *The sampling point distribution over the Hongze Lake*

Table 1: *The corresponding areas for the sampling points of the Hongze Lake*

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 River estuary
HZ10	Sanhe floodgate

The study conducted by Kim et al. [11] indicates that the effects of wind scale and wind direction on algae density distribution exhibits a certain lag; generally, the lag is around 3-15d. Referencing to the lagged effects of wind scale and wind direction on algae density distribution of the Taihu Lake [12], this study uses the mean value of daily wind scale and wind direction data of the 8 days before the sampling time (including the sampling day) as the characterization variable. Specifically, the calculation equation is as follows:

$$W = [\Sigma(S_i \times F_i)]/8$$

In the equation above, W denotes the mean value of wind effect of the 8 days before the sampling time (including the sampling day); S_i denotes the wind scale of the i-th day; F_i denotes the wind direction of the i-th day, $-1 \leq F \leq 1$, where $F_i = -1$ for wind scale ≥5, $F_i = 1$ for vertical onshore wind with a scale ≤4, and $F_i = -1$ for offshore wind.

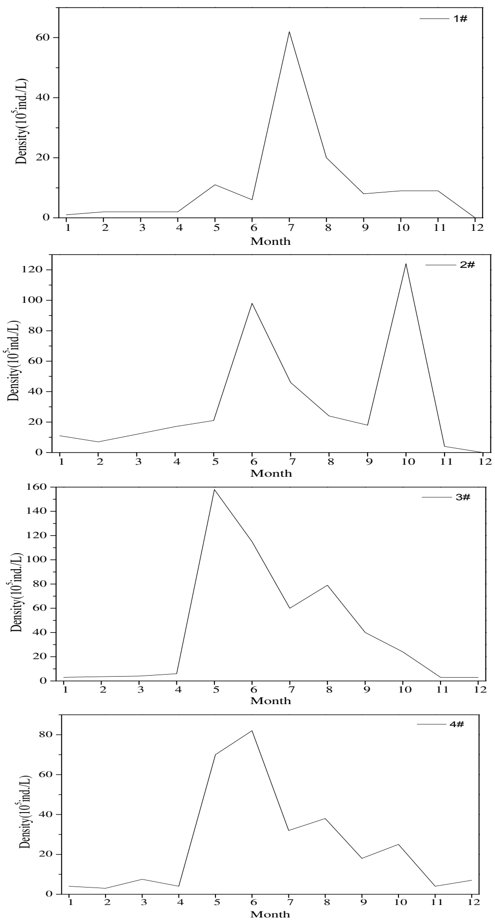
2.3 Data analysis method:

The correlations of algae density with water quality and wind effect are analyzed using the Partial Correlation Analysis component in SPSS18.0.

3. Results:

3.1. The temporal and spatial distribution of algae density in the Hongze Lake:

Figure 2 shows the seasonal variation of the algae density in each sampling point. The algae density is $0.4\sim65\times10^5$ind./L at point 1#, $0.13\sim97.0\times10^5$ind./L at point 2#, $5.0\sim10^6\times10^5$ind./L at point #3, $6.4\sim83\times10^5$ind./L at point 4#, $0.16\sim15.5\times10^5$ind./L at point 4$, $0.1\sim17\times10^5$ind./L at point 6#, $0.24\sim30.6\times10^5$ind./L at point 7#, $0.53\sim14\times10^5$ind./L at point 8#, $3.4\sim44\times10^5$ind./L at point 9# and $0.44\sim60\times10^5$ind./L at point 10#. According to Figure 2, the seasonal variation of algae density is not consistent among different sampling points. The algae density at point 2# exhibits two peaks, one in summer and one in autumn; the algae density of point 5# - 9# only exhibits a lower peak in early summer; while the algae density of other points exhibits a single peak in summer. The lowest value of algae density generally appears in winter. It is noteworthy that the algae density of point 5# - 9# decreases after July, which is mainly caused by the exchange of water in the Hongze Lake. The microscope examination shows that, during the summer peak season, the algae are mainly composed of high-density microcystis, oscillatoria, spirulina, anabaena and raphidiopsis (cyanobacteria), as well as ulothrix and diatom (chlorophyta).



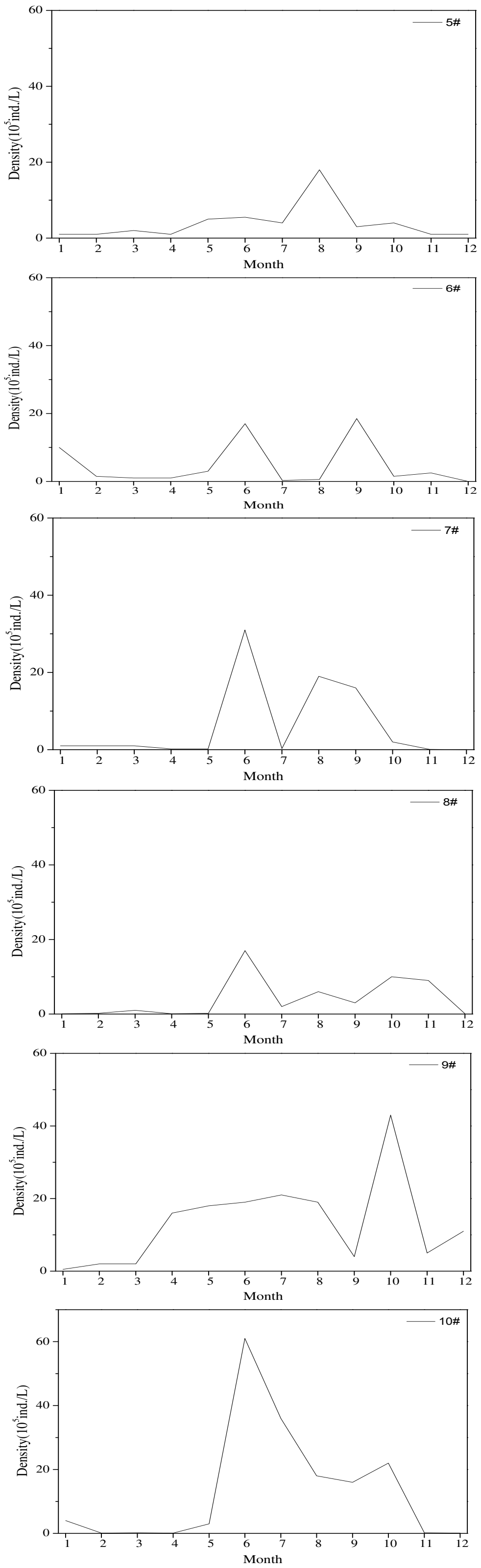


Figure 2: *The seasonal variation of the density of phytoplankton in the Hongze Lake*

Figure 3 shows the annual mean value of algae density at each sampling point. In terms of spatial comparison, the annual mean value of algae density of the 10 sampling points forms the follow ranking:

5#<8#<6#<7#<1#<10#<9#<4#<2#<3#. The annual mean value is in the range of 4.4～40×10^5ind./L. Except for point 5# - 8#, the algae density of other points is greater than 10^6ind./L.

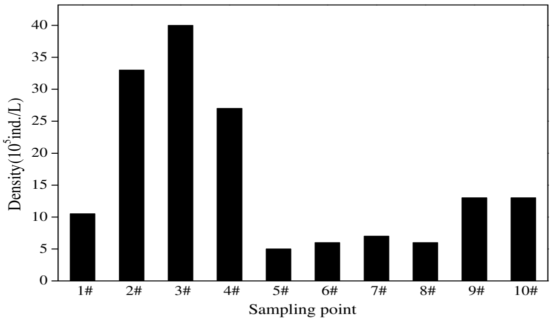


Figure 3: *The annual mean value of phytoplankton density in the Hongze Lake*

3.2. The temporal and spatial distribution of TN and TP:

The concentration of TN is in the range of 1.10-4.76mg/L, with the mean value of 2.16mg/L. The concentration of TN reached the peak value in the period of December 2012 to June 2013, and then began to decrease. The concentration of TP is in the range of 0.036-0.473mg/L, with the mean value of 0.129mg/L. The concentration of TP is the lowest in April, with the value of 0.055mg/L, and the highest in August, with the value of 0.473mg/L; the seasonal variation trend is insignificant (Figure4). In terms of the spatial pattern, the variations of TN and TP are basically consistent. The lowest values are both detected at the Chengzi Lake (3# and 4#) and the Linhuai (9#) monitoring points, while the highest values are detected in the open water district (5#, 6#, 7# and 8#)(Figure5). The concentrations of nutrient salts are generally high all over the Hongze Lake, which has satisfied the growing need of algae. Therefore, nutrient salts may not be the main limiting factor for the growth of algae.

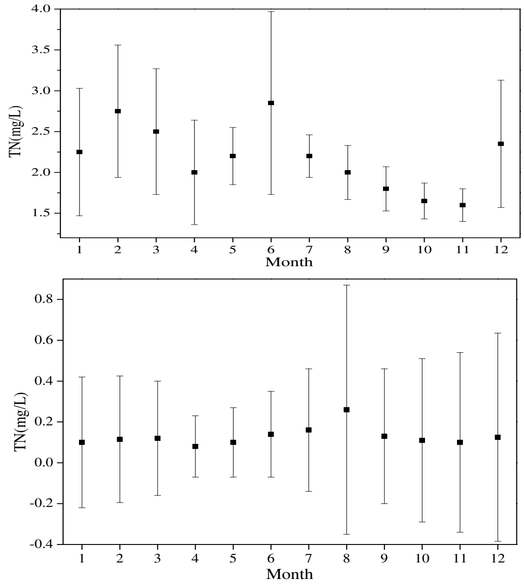


Figure 4: *The seasonal variation of TN and TP in the Hongze Lake*

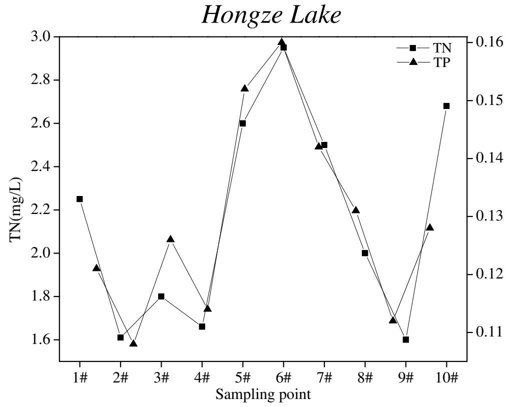


Figure 5: *The spatial distribution of TN and TP in the Hongze Lake*

3.3 The distribution characteristics of wind scale and water level

Table 2 shows the monthly data of wind speed, wind direction and the water level of main monitoring points of the Hongze Lake in 2013.

Table 2: *wind speed, wind direction and the water level of main monitoring points of the Hongze Lake*

Month	wind direction	wind direction (m/s)	1# water level (m)	3# water level (m)	6# water level (m)	10# water level (m)
1	NE	7.9	13.02	13.08	13.06	13.1
2	NE	9.7	13.16	13.22	13.25	13.27
3	ENE	14.2	13.28	13.35	13.4	13.37
4	NE	10.9	12.94	13.02	12.97	12.99
5	ENE	7.6	12.64	12.63	12.59	12.61
6	NE	8.9	12.68	12.69	12.79	12.79
7	W	7.8	11.93	11.73	12.06	11.9
8	SW	7.9	12.6	12.61	12.54	12.57
9	WNW	9	11.68	11.65	11.7	11.68
10	NE	9	12.87	12.85	12.89	12.91
11	W	9.8	12.81	12.71	12.71	12.77
12	W	9	12.88	12.82	12.8	12.83

According to Table 2, the wind scale in summer is smaller than that in spring, so it is inappropriate to investigate the effect of wind scale on algae distribution cross the quarters. Based on the results of perennial monitoring, an alga generally begins to grow in May, and show the sign of outbreak in June. Thereafter, the possibility of outbreak remains until the end of October. The wind direction of the Hongze Lake is mainly northeast from January to June, and west from July to December. The change of wind direction in July can influence the distribution of algae in the lake. It plays a certain role in driving a large number of algae to drift toward the sampling points 1# to 4#.

3.4 Analysis of the correlations of algae density with the water quality factor and wind effect:

The method of partial correlation analysis is used to analyze the correlations of algae density with ρ (TN), ρ (TP) and wind effect. The results are shown in Table 3. According to Table 3, the algae density is not correlated with TN, TP and wind effect in spring, and positively correlated with the concentration of TN in summer (the correlation coefficient is 0.791, P=0.084). The absolute value of the partial correlation coefficient reflects the degree of correlation. The partial correlation coefficients suggest that algae density is mainly influenced by wind scale in spring, and by the concentrations of TN and TP in summer.

Table3: *The result of partial correlation analysis between algae density and water factors, wind function*

Items	spring		Summer	
	correlation coefficient	P	correlation coefficient	P
TN	-0.165	0.894	0.791	0.084
TP	-0.051	0.968	-0.700	0.506
wind function value	-0.890	0.301	-0.178	0.886

4. Discussion:

4.1 The relationship between the water quality factor and the temporal and spatial distribution of algal density:

The correlation between the algae density and the concentrations of N and P has always been a focus of concern among scholars. In this study, the partial correlation analysis indicates that algae density is not correlated with TN, TP and wind effect in spring. The reason is that microcapsule hypopus begin to enter the germination stage under suitable environmental conditions in spring [13, 14], which will reduce the transparency of the lake water; as long as N and P nutrients are sufficient (in spring, TN>2mg/L and TP>1mg/L), algae will keep growing, and the N and P nutrients affixed to the lake bottom will supply the nutrients absorbed by algae continuously. Thus, algae density will not reduce the concentrations of N and P; in other words, algae density is not correlated with N and P. For algae growing in large lakes, due to the cycling of nutrient salts, the exchange between sediments and water interface, as well as the microbial processes, the nutrient salts required by algae growing can usually regenerate, not necessarily relying on external inputs [15]. Therefore, compared to algae growing in smaller lakes, algae growing in larger lakes are less influenced by nutrient salts [16, 17]. As China's fourth largest freshwater lake, the Hongze Lake has a rich reserve of nutrients, so its algal density distribution in spring is almost unrestrained by the concentrations of TN and TP. However, in summer, the algae density is positively correlated with the concentration of TN, indicating that the massive propagation of algae severely depletes the nutrient salts in the water body. As a consequence, nitrogen nutrient becomes a limiting factor for algal bloom. This finding differs from the research outcome of the Taihu Lake. The algae density distribution of the Taihu Lake has no significant correlation with both N and P nutrients in the water body around the shore area of the Taihu Lake [18]. Thus, the eutrophication of the Hongze Lake is less severe than that of the Taihu Lake.

4.2 The relationship between wind effect and the temporal and spatial distribution of algal density：

The spatial distribution of algae density of the Hongze Lake is not significantly influenced by wind scale and wind direction. Especially in the summer, wind effect almost imposes no impact on the algal density distribution. This is probably because that the wind scale in summer is too small, not enough to produce any impact on the algal density distribution. This finding also differs from the research outcome of the Taihu Lake. The study conducted by Fan Chengxin, et al. [19] shows that, during the outbreak of cyanobacteria bloom in the northern part of the Taihu Lake, the prevailing wind in summer can drive the floating mat-like bloom to drift toward the Meiliang Bay located on the north of the Taihu Lake and intensify the bloom of the Meiliang Bay. The follow-up study conducted by Bai Xiaohua, et al. [20] about the bloom of the Taihu Lake in the summer of 2004 reveals that, during the 6d of bloom outbreak, the bloom drifted from the Great Taihu Lake to the Meiliang Bay in 5d, occupying 3.7%-13.3% of the total area of the Meiliang Bay.

In addition, the impacts of wind effect on the algae density distribution in different seasons are incomparable. Table 2 shows that the mean value of wind effect in spring is higher than that in summer, but the mean value of algae density in spring is obviously lower than that in summer. This suggests that for the impact of wind effect on the algae density, wind is the extrinsic factor, while the amount of algae or algae density is the intrinsic factor. The effect of extrinsic factor depends on the intrinsic factor. The wind effect can impact the relative distribution of algae density, but the algae density at different times is more directly influenced by seasons. The change of temperature in different seasons can affect the photosynthesis, respiration and growth rate of algae.

The rise of temperature is one of the important reasons that lead to the growing advantage of cyanobacteria; especially in summer, cyanobacteria is more adaptable to the high temperature environment [21]. Research findings suggest that the variation of water temperature is basically consistent with the changing trend of the production amount of algae; they both reach the peak value in summer.

4.3 Other factors that may influence the temporal and spatial distribution of algae density：

The water quality of inlet rivers and the lake current pattern can influence the algae density distribution of the Hongze Lake to a certain extent. The Huaihe River is the main inlet river of the Hongze Lake. It contains a large number of tributaries, among which, there are 4 first-tier tributaries occupying a watershed area over 10000 km^2 each, 16 first-tier tributaries occupying a watershed area over 2000 km^2 each, and 21 first-tier tributaries occupying a watershed area over 1000 km^2 each. Because of the extensive coverage of basin area, many big cities and industrial sectors are located along the Huaihe River. The massive discharge of sewage and waste gas has caused serious pollution to the Huaihe River. A lot of villages along the Huaihe River and its tributaries often appear the breakout of serious diseases. Meanwhile, the supervision of the local government is far behind enough, and the public awareness of environmental protection is extremely limited. As a consequence, the water environment problem of the Hongze Lake is becoming increasingly serious. From 1991 to 2009, the Hongze Lake experienced more than 80 cases of water pollution incidents, including 3 very severe incidents, 13 severe incidents, 10 major incidents and 59 general incidents. These water pollution incidents would certainly supply a large amount of N, P and other nutrients into the Hongze Lake, which created a favorable condition for the growth of phytoplankton. The high-nutrient pollution of the inlet rivers is an important cause of the primary algae in the Hongze Lake.

Lake current is a physical quantity that characterizes the water flow rate and direction of a lake. It can reflect the water exchange rate and intensity between different regions of a lake, and is the main source of energy for the transportation of nutrients, sediments and planktons (including algae); therefore, lake current is the main factor that influences the lake ecology and environment [24]. Generally speaking, the lake current of shallow lakes consists of two types, wind-driven current and inlet/outlet current. As a large pass-through shallow lake, the inlet/outlet volume of the Hongze Lake is very huge, particularly around the inlet of the Huaihe River on the west, the Sanhe Sluice on the south, and the outlet of North Jiangsu Province irrigation gate on the southeast. Thus, the southern part of the Hongze Lake has a large outlet flow rate, which may reduce the algae density at sampling points 1# and 5# - 10#. In contrast, the sampling points located at the northern part (2#, 3# and 4#) are less influenced by lake current, so the algae density of these points is far higher than that in other points.

5. Conclusion：

(1)The temporal and spatial distribution of algae density of the Hongze Lake is very obvious. The mean value of algae density is 12.3×10^5ind./L in spring and 32.9×10^5ind./L in summer. Generally speaking, the algae density of the northern part is higher, and the density of the western and southern part is lower.
(2)The temporal and spatial distribution of the water quality factor exhibits significant differences. The water quality of the Hongze Lake is heavily affected by the water quality of the Huaihe River. The concentrations of TN and TP are highest at sampling points 5#, 6# and 7#, which are located around the inlet of the Huaihe River, while the concentrations of TN and TP are relatively low at sampling points 2#, 3#, 4# and 9#, which are located far away from the Huaihe River. In terms of seasons, the concentrations of TN and TP are higher in summer than in spring.
(3)Wind effect does not impose a significant impact on the algae density distribution of the Hongze Lake.
(4)The algae density distribution of the Hongze Lake is influenced by the inlet/outlet rivers and the lake current. The high-nutrient pollution of the inlet rivers is an important cause of primary algae. Because of the pass-through characteristic, the algae density along the current channel is lower, while the density far away from the current channel is relatively higher.

6. Acknowledgements:

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