Analysis and Research on the Pollution of Lakes in Beijing

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Abstract: This article analyzes the pollution status of 22 key lakes in Beijing in the past 10 years. The results show that from 2010 to 2014, the proportion of lakes in Beijing's Class II water bodies was 17.4%, and the average proportion of lakes in Class III water bodies from 2015 to 2020 was 29.2%; the decline in the proportion of Class V water bodies from 2016 to 2020 was more obvious. Water bodies inferior to Class V have been basically eliminated, but in 2019, many lakes have been in a state of moderate eutrophication. At the same time, the analysis during the year showed that the proportion of Type II water bodies was low from June to September, the lowest value was 11.7% in August, and the proportion was relatively high in February and March, and the highest value was 40.5% in March; In August, the proportions of Category IV and V water bodies reached the highest values of 33% and 24% respectively, which is related to the increase in summer water temperature and the shortage of water resources that can supply lakes. The research results are expected to provide support for the improvement of urban lake water environment.

1. Introduction
Urban lakes are an important part of the urban landscape, which can not only improve the quality of the urban environment, but also provide recreational and sports venues. And it has the function of maintaining the balance of the local ecosystem, regulating the climate, and enriching the urban biodiversity \cite{1,2}. However, urban lakes often have poor water body fluidity\cite{3}, small water area, insufficient water distribution, and small water environment capacity, which make the water ecosystem unsound and the water environment deterioration problem is more serious. The author of this paper conducts statistics on the pollution status of 22 key lakes in Beijing from 2010 to 2020, understands the characteristics of urban lake pollution changes in Beijing in the past 10 years, analyzes the main causes of lake pollution, and proposes targeted solutions. In order to provide a reference for the improvement of the water environment of urban lakes.

2. Pollution status of urban lakes in Beijing

2.1. Characteristics and distribution of urban lakes in Beijing
The water area of Beijing city lakes is about 7.3km\textsuperscript{2}, and the water depth is generally 1.5-2.0m\cite{4}. It has the characteristics of multi-source water supply, single hydrodynamic conditions, and large impact of non-point source pollution. The specific distribution of lakes is shown in Figure 1. Among them, the
lakes that use the Jingmi Water Diversion Canal as the water source are Shichahai, Tongzi River, Zizhuyuan Lake, Honglingjin Lake, Olympic Lake, Liuyin Park Lake, Qingnian Lake, Tuancheng Lake, Kunming Lake and Exhibition Hall Houhu; Yongding River is used as a water source. The lakes whose canals are the water source include Yuyuantan Lake, Bayi Lake, Lotus Pond, Taoranting Lake, and Longtan Lake.

Fig.1. River and lake water system map of Beijing

2.2. The pollution status of urban lakes in Beijing changes over time

2.2.1. Interannual variability
The pollution status of lakes in Beijing from 2010 to 2020 is shown in Figure 2 and Figure 3. The number of lakes in Class II water bodies is on the rise, accounting for an average of 17.4% before 2015 and 29.2% after 2015. The percentage of lakes in category III water bodies varies from 5.9% to 64.7%. In 2013, the annual average value of category II water bodies was 16.5%, and the highest in 2019 was 34.7%. The overall trend was first down and then up, with an average of 26.6%. The proportion of lakes in Category IV and V water bodies showed a significant downward trend. From 2010 to 2016, the average proportions of Category IV and Category V water bodies were 28.2% and 19.2% respectively. From 2017 to 2020, and the proportions of Category IV and Category V water bodies were 22.3% and 12.5% respectively.
Fig. 2. Inter-annual changes in water pollution of urban lakes in Beijing from 2010 to 2020

Note: The data is quoted from the Water Resources Bulletin of Beijing Water Affairs Bureau (2010-2020)

According to the evaluation data of the nutritional status of 22 lakes in Beijing released by the Beijing Municipal Water Affairs Statistical Yearbook, a statistical analysis of the changes in the nutritional status of 22 lakes from 2016 to 2019, including Bayi Lake, Yuyuantan Lake, Beihai, Zhonghai, Nanhai, Tongzihe, Qingnian Lake and Olympic Lake have been in a state of mild eutrophication. Tuancheng Lake, Kunming Lake and Exhibition Hall Houhu Lake have better water quality, and they are all in a mesotrophic state. From 2016 to 2018, most of the 22 lakes will be monitored for mild eutrophication. In 2019, Taoranting Lake, Chaoyang Park Lake, Lianhua Pond and Liuyin Park Lake were in a moderate eutrophication state. According to research and analysis, the ecological environment water consumption in 2019 was the highest value from 2010 to 2019 of 1.466 billion m³, but the surface water resources were only 861 million m³, and the water transferred from the South-to-North Water Diversion Project was 985 million m³. Considering the evaporation and leakage of rivers and lakes, it is difficult for the upstream water to meet the needs of ecological environment, resulting in poor hydrodynamic conditions of the lakes, long replacement cycles, and overall deviations in the quality of the water environment.

Table 1. Evaluation table of the nutritional status of urban lakes from 2016 to 2019

| Name            | 2019 EI Index | Nutritional status level | 2018 EI Index | Nutritional status level | 2017 EI Index | Nutritional status level | 2016 EI Index | Nutritional status level |
|-----------------|---------------|---------------------------|---------------|---------------------------|---------------|---------------------------|---------------|---------------------------|
| Tuancheng Lake  | 42            | Medium nutrition          | 44            | Medium nutrition          | 46            | Medium nutrition          | 45            | Mild eutrophication       |
| Kunming Lake    | 47            | Medium nutrition          | 47            | Medium nutrition          | 53            | Mild eutrophication       | 49            | Mild eutrophication       |
| Old Summer Palace Lake | 54  | Mild eutrophication  | 49            | Medium nutrition          | 50            | Mild eutrophication       | 52            | Mild eutrophication       |
| Bayi Lake       | 54            | Mild eutrophication       | 51            | Mild eutrophication       | 55            | Mild eutrophication       | 57            | Mild eutrophication       |
| Yuyuantan       | 55            | Mild eutrophication       | 54            | Mild eutrophication       | 57            | Mild eutrophication       | 58            | Mild eutrophication       |
### Note
The data is quoted from the Beijing Municipal Water Affairs Statistical Yearbook (2016-2019)

### 2.2.2. Changes during the year
The annual changes in the pollution status of Beijing’s lakes in the past 10 years are shown in Figure 3. The percentage of lakes with Type II water bodies was low from June to September, and the lowest value was 11.7% in August. The percentage was relatively high in February and March, and the highest value was 40.5% in March; the proportion of Category IV and V water bodies accounted for a relatively high proportion from June to September, and the highest values were 33% and 24% in August.

After analysis, temperature, as an important physical feature of lakes, has an impact on the survival, growth and spatial distribution of lake organisms\(^{[5-8]}\). The increase in summer temperature promotes the decomposition of humus of submerged plants by heterotrophic microorganisms and causes sediment humus. The degree of chemistry increased\(^{[9]}\). At the same time, the increase in temperature has an important impact on water quality indicators. The increase in temperature will increase the release of phosphorus from the sediments. Studies have shown that when the water temperature increases by 3-4°C, the release of P will double\(^{[10]}\). At the same time, temperature will also participate in the whole process of algae recovery and growth. As the water temperature rises, algae will multiply, and lake eutrophication will increase\(^{[11-12]}\).

| Lake Name          | Type of Eutrophication | Medium Nutrition | Mild Eutrophication | Total Percentage |
|-------------------|------------------------|------------------|---------------------|-----------------|
| Zizhuyuan Lake    | Mild eutrophication    | 55               | 49                  | 54              |
| West Sea          | Medium nutrition       | 48               | 51                  | 56              |
| Houhai            | Medium nutrition       | 46               | 48                  | 52              |
| Qianhai           | Medium nutrition       | 46               | 47                  | 53              |
| North Sea         | Mild eutrophication    | 54               | 51                  | 57              |
| Middle sea        | Mild eutrophication    | 52               | 52                  | 58              |
| South China Sea   | Mild eutrophication    | 53               | 52                  | 56              |
| Exhibition Hall Lake | Medium nutrition       | 48               | 44                  | 52              |
| Tongzi Lake       | Mild eutrophication    | 51               | 53                  | 56              |
| Taoranting Lake   | Mild eutrophication    | 63               | 58                  | 63              |
| Longtan Lake      | Mild eutrophication    | 57               | 58                  | 64              |
| Youth Lake        | Mild eutrophication    | 57               | 60                  | 59              |
| Chaoyang Park Lake | Mild eutrophication    | 63               | 57                  | 59              |
| Red Scarf Lake    | Mild eutrophication    | 60               | 57                  | 60              |
| Lotus pond        | Medium nutrition       | 64               | 65                  | 59              |
| Olympic Lake      | Mild eutrophication    | 55               | 55                  | 54              |
| Liujuin Park Lake | Medium nutrition       | 64               | 68                  | 72              |
3. Analysis on the Causes of Urban Lake Pollution in Beijing

In order to preliminarily explore the response relationship between the pollution status of Beijing’s urban lakes and hydrological water quantity, the annual precipitation, surface water resources, available water inflow from Miyun Reservoir, available water in Guanting Reservoir, and water inflow from the South-to-North Water Diversion Project are now calculated. The ecological environment water consumption, reclaimed water utilization and river and lake replenishment water consumption are counted, and the results are shown in Table 2 below.

### Table 2. 2010-2019 Beijing Water Resources Development and Utilization Statistics Table

| Indicator name                        | Unit of measurement | 2010year | 2011year | 2012year | 2013year | 2014year | 2015year | 2016year | 2017year | 2018year | 2019year |
|---------------------------------------|---------------------|----------|----------|----------|----------|----------|----------|----------|----------|----------|----------|
| Annual precipitation                  | mm                  | 524      | 552      | 708      | 501      | 439      | 583      | 660      | 592      | 590      | 506      |
| Surface water resources               | Billion m³          | 7.22     | 9.17     | 17.95    | 9.43     | 6.45     | 9.32     | 14.01    | 12.03    | 14.32    | 8.61     |
| Groundwater resources                 | Billion m³          | 15.86    | 17.64    | 21.55    | 15.38    | 13.8     | 17.44    | 21.05    | 17.74    | 21.14    | 15.95    |
| Miyun Reservoir available water      | Billion m³          | 2.94     | 4.1      | 3.04     | 4.42     | 1.59     | 3.16     | 6.82     | 4.76     | 7.2      | 1.97     |
| Available water in the Guanting      | Billion m³          | 1.13     | 0.46     | 0.22     | 1.64     | 0.46     | 0.93     | 1.67     | 1.08     | 1.72     | 2.75     |
| Reservoir South-to-North Water       | Billion m³          | 2.55     | 2.75     | 2.8      | 3.68     | 0.84     | 8.81     | 10.63    | 10.77    | 11.92    | 9.85     |
| Diversion Project                    | Billion m³          | 3.97     | 4.47     | 6.52     | 7.08     | 8.37     | 10.12    | 11.1     | 12.17    | 12.45    | 14.66    |
3.1. Resource shortage

The clean water diversion project is an important measure to improve the quality of lake water environment and improve the self-purification ability of water bodies[13]. Beijing’s urban lakes are mainly supplied by reclaimed water, Guanting Reservoir, Miyun Reservoir and South-to-North Water Diversion. Since 1999, Beijing has suffered continuous drought, with an average annual precipitation of only 475mm. Through the correlation analysis of the factors in Table 2 above, it is further found that the average annual precipitation in Beijing from 2010 to 2019 is significantly positively correlated with the amount of surface water resources (P<0.01). The reason is that Beijing is located in the northern part of the North China Plain and belongs to a temperate continental monsoon climate. Summer precipitation is strong and fluctuating. Table 2 shows that the “7.21” heavy rain in 2012, with a maximum rainfall of 708 mm; however, the rainfall in 2014 the volume is only 439mm. At the same time, there is a serious shortage of surface water resources. Since 2014, the South-to-North Water Diversion Project has supplied water to Beijing, reducing the output of Miyun Reservoir by more than 50,000 m³ every year[14].

In 2014, the usable inflow of Miyun Reservoir and Guanting Reservoir was reduced to 159 million m³ and 46 million m³, respectively. Correlation analysis showed that the ecological environment water demand was significantly negatively correlated with the available water volume of Miyun Reservoir and the water transferred from the South-to-North Water Diversion Project (P<0.01), and the ecological environment water consumption was significantly positively correlated with the recycled water utilization (P<0.01). Almost all of the ecological environmental water demand is used for replenishment of rivers and lakes. Therefore, the replenishment of urban lakes in Beijing mainly comes from recycled water. The water resources of Guanting Reservoir and Miyun Reservoir are becoming increasingly scarce, and the demand for reclaimed water as an important source of water supply for Beijing’s lakes is increasing year by year.

### Table 3. Correlation analysis of hydrological and water quantity factors in Beijing from 2010 to 2020

|                      | Annual precipitation | Surface water resources | Miyun Reservoir available water | South-to-North Water Diversion Project | Ecological water consumption | Reclaimed water utilization |
|----------------------|----------------------|-------------------------|-------------------------------|---------------------------------------|----------------------------|----------------------------|
| Annual precipitation | 1                    |                         |                               |                                       |                           |                            |
| Surface water resources | 0.91**                | 1                       |                               |                                       |                           |                            |
| Miyun Reservoir available water | 0.104                | 0.259                   | 1                             |                                       |                           |                            |
| South-to-North Water Diversion Project | 0.349                | 0.352                   | 0.782**                       | 1                                    |                           |                            |
| Ecological water consumption | 0.313                | 0.257                   | -0.352**                      | -0.184**                             | 1                          |                            |
| Reclaimed water utilization | 0.523                | 0.473                   | -0.07**                       | -0.136**                             | 0.362**                    | 1                          |

Note: The significance level is set to 0.05; * means P<0.05, significant correlation; ** means P<0.01, extremely significant correlation.

3.2. Single hydrodynamic conditions

A certain level of water fluidity is a necessary guarantee for the health of lakes. Insufficient water in the upper reaches of urban lakes leads to long water exchange cycles in lakes. Under suitable meteorological conditions, slower flow speeds slow the diffusion of local nutrients in the water body, which easily leads to eutrophication of the water body. The occurrence of chemical state[15].
At the same time, the low flow rate can promote the increase of water temperature and lengthen the hydraulic retention time, on the other hand, the living environment of the algae is relatively stable under the low flow rate\cite{16}. Zhou Jing\cite{17} found that low flow rate is more conducive to the growth of algae, and the growth of algae is inhibited at high flow rate. Zhao Ying\cite{18} found that when the flow velocity is greater than 0.5m/s, the flow velocity has a significant inhibitory effect on algae.

3.3. Non-point source impact
In recent years, there have been many studies on the impact of heavy rains on lake water quality. On the one hand, the initial rainwater will carry a large amount of acid gases in the air, car exhaust and other polluting gases into the river, and it will also cause the lake’s pH value to gradually drop. Threat\cite{19-22}, and the lake pH value will also control the circulation of sediment phosphorus\cite{23-25}. On the other hand, through the analysis of monthly precipitation and lake water quality in Beijing in 2012, there is a significant positive correlation between the number of lake water bodies in Category V and precipitation (P<0.05). It can be seen from Figure 2 that the analysis of the relationship between the monthly precipitation and lake water quality from 2010 to 2020 shows that the water bodies of Category IV and V accounted for a relatively high proportion during the flood season (June to September).

At the same time, extreme rainstorms will increase the concentration of water particles, affecting hundreds of square kilometers\cite{26}. Nutrients carried by rainstorm runoff pose great challenges to the control of lake eutrophication\cite{27}.

Table 4. 2012-2019 urban rain and sewage combined pipeline length and sewage discharge statistics

| Indicator name                          | unit of measurement | 2012year | 2013year | 2014year | 2015year | 2016year | 2017year | 2018year | 2019year |
|-----------------------------------------|---------------------|----------|----------|----------|----------|----------|----------|----------|----------|
| Rain and sewage confluence pipeline    | km                  | 2122     | 2104     | 2198     | 2232     | 1695     | 1574     | 1490     | 1528     |
| Sewage discharge                        | Ten thousand m$^3$  | 152010   | 155317   | 161548   | 164217   | 169748   | 187267   | 203703   | 211209   |

Note: The data is quoted from the Beijing Municipal Water Affairs Statistical Yearbook (2012-2019)

On the other hand, in recent years, the amount of sewage discharge in Beijing has been increasing, and the combined rain and sewage pipelines still account for a large proportion. The problems of the dissolution of urban road garbage and dust and the overflow of sewage into the river are serious.

4. Lake pollution prevention and control measures

4.1. Improve relevant laws and regulations
The prevention and control of pollution in rivers and lakes not only requires a concentrated demonstration of public morality and responsibility from all walks of life in society, but also requires strong guarantees of national laws and regulations. Raise sewage discharge standards and strictly implement the penalty system; in accordance with the water quality requirements of different water function zones, the pollution-holding capacity of water bodies shall be verified, and different receiving standards shall be formulated for different rivers and lakes. Strengthen the government's ability to manage and control rivers, strengthen the responsibilities of the government and enterprises, and establish a sound management and control system.

4.2. Strengthen multi-departmental coordination and management
Implement the "river chief system" and "lake chief system", establish a water environment monitoring and evaluation system, implement multi-departmental joint management and control, coordinate reclaimed water and upstream water quality management ideas and guidelines; give full play to the "river chief + sheriff + inspector" linkage Mechanism, work together to rectify the problem of water
pollution. Establish an interoperable river management platform and strengthen the close cooperation between the river management office and the government. Ensure that enterprises meet green emission standards, control agricultural non-point source pollution, and reduce the input of nitrogen and phosphorus in rivers.

4.3. Improve the treatment level of sewage treatment plants
With the rapid development of my country’s industry and the continuous improvement of people’s living standards, the composition of various sewage and wastewater has become more complex, and my country’s comprehensive sewage discharge standard has also been upgraded from (GB8978-1996) to (DB11/307-2013). However, it cannot solve the contradiction between today’s social development and the ecological environment. In order to better meet the requirements of ecological civilization construction and earnestly implement pollution prevention and control, it is necessary to strengthen the supervision and management of sewage treatment plants by government departments, and to Continue to increase efforts to upgrade standards, innovate sewage treatment technology, raise sewage discharge standards, and improve sewage treatment capacity.

4.4. Strengthen research on the mechanism of water eutrophication
The eutrophication of water body is affected by multiple factors. In the process of eutrophication research, it is necessary to comprehensively consider the interaction between hydrometeorological factors, hydrodynamic conditions, the influence of submerged plant adsorption and allelopathy, and the release of nutrients in sediments. Interaction relationship, in-depth multi-disciplinary research, to explore the mechanism of algal blooms, establish a water bloom early warning model, so as to do a good job in the prevention and control of water eutrophication.

4.5. Enhancing the diversity of water ecosystems
The achievement of water environmental governance standards should be based on the diversity of the water ecosystem as an assessment indicator, and the health of the water environment should be the ultimate goal. Therefore, on the basis of the overall treatment of source control and pollution interception and ecological restoration, precise measures are taken on polluted rivers, and on the basis of controlling the concentration of nitrogen and phosphorus in the upstream water, aquatic plant belts are constructed to increase the types of benthic organisms and create complex The aquatic ecosystem realizes the natural succession of algae and aquatic plants, while avoiding the overgrowth of a single species, and constructing a biological chain structure of "plankton-plankton-benthic organisms-fish" to improve the self-purification ability of rivers and lakes and realize shore green The situation is clear.

5. Conclusion
With the advancement of my country's ecological civilization construction and the implementation of environmental protection related policies, the pollution situation of urban lakes in Beijing has improved significantly in the past 10 years. The number of lakes in Class II water bodies has increased significantly, and the number of lakes in Class IV-V water bodies has decreased significantly. As of 2019, the monitored area of lakes in Beijing is 719.6hm², the area that meets the water quality standards of II-III is 535.6hm², and the area that meets the water quality standards of IV-V is 184.0hm². However, in recent years, the number of moderately eutrophic lakes has been on the rise, and the pollution status of urban lakes is not optimistic. Therefore, comprehensive consideration of the direct or indirect factors related to lake health and the establishment of a sound water environment management system are of great significance to the improvement of the water environment quality of urban lakes.

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References

[1] Ouyang Zhiyun, Zhao Tongqian, Wang Xiaoke, Miao Hong. Analysis of water ecological service function and its indirect value evaluation[J]. Acta Ecologica Sinica, 2004(10):2091-2099.

[2] Shen Yanyi, Chen Xing. Research on Health Evaluation and Restoration of Urban Lake Ecosystem[J]. Journal of Water Resources and Water Engineering, 2017, 28(02): 82-85+91.

[3] Jiang Xiaoying, Xia Ting, Pan Xin, Yang Junyan, Xu Yong. Characteristics of temporal and spatial variability of water quality in Suzhou lake source area[J]. China Rural Water and Hydropower, 2020(09): 190-195+201.

[4] Jing Hongwei, Hua Lei, Sun Chenghua, Guo Jing. Evaluation and analysis of eutrophication of urban lakes in Beijing[J]. Lake Science, 2008(03):357-363.

[5] JoAnna L. Lessard, Daniel B. Hayes. Effects of elevated water temperature on fish and macroinvertebrate communities below small dams[J]. River Research and Applications, 2003, 19(7).

[6] M. D. MacKay, P. J. Neale, C. D. Arp, L. N. De Senerpont Domis, X. Fang, G. Gal, K. D. Jöhnk, G. Kiritilin, J. D. Lentes, E. Litchman, S. MacIntyre, P. Marsh, J. Melack, W. M. Mooij, F. Peeters, A. Quesada, S. G. Schladov, M. Schmid, C. Spence, S. L. Stokesr. Modeling lakes and reservoirs in the climate system[J]. Limnology and Oceanography, 2009, 54(6part2).

[7] GEOFFREY C. POOLE, CARA H. BERMAN. An Ecological Perspective on In-Stream Temperature: Natural Heat Dynamics and Mechanisms of Human-Caused Thermal Degradation[J]. Environmental Management, 2001, 27(6).

[8] Hawkins Charles P., Hogue James N., Decker Lynn M., Feminella Jack W.. Channel Morphology, Water Temperature, and Assemblage Structure of Stream Insects[J]. Journal of the North American Benthological Society,1997,16(4).

[9] Chen Mo, Zhang Yaqing, Li Jiaxuan, Jiao Yiying, Zhao Liya, Xu Feng, Song Na. The effect of temperature on the anaerobic decomposition of submerged plant residues in lake sediments[J]. Journal of Environmental Sciences, 2020, 40(08): 3013-3019.

[10] Kenneth H. Nicholls. Effects of Temperature and Other Factors on Summer Phosphorus in the Inner Bay of Quinte, Lake Ontario: Implications for Climate Warming[J]. Journal of Great Lakes Research,1999,25(2).

[11] J.M. Malmaeus, T. Blencner, H. Markensten, I. Persson. Lake phosphorus dynamics and climate warming: A mechanistic model approach[J]. Ecological Modelling,2005,190(1).

[12] Huang Wei. Comprehensive management of cyanobacteria bloom and water eutrophication[J]. China Rural Water and Hydropower, 2014 (04): 44-50+54.

[13] Yu Mingyong, Zhang Hai, Yu Xiangjing. Research on the water environmental water demand of Changhu Lake and its diversion to the Qinghai Lake[J]. China Rural Water and Hydropower, 2013(06): 21-25.

[14] Ye Yuting. The influence of temperature on chlorophyll a and main water quality indexes of Taihu Lake[D]. Nanjing University, 2019.

[15] Zhu Lili, Zhang Lu, Li Huanping, Xie Mengwei, Jiang Jiezeng. Research progress in eutrophic water purification[J]. Green Science and Technology, 2017(04): 44-46+49.

[16] V. Acuña, C. Vilches, A. Giorgi. As productive and slow as a stream can be—the metabolism of a Pampean stream[J]. Journal of the North American Benthological Society,2011,30(1).

[17] Zhou Jing, Gou Ting, Zhang Luohong, Lan Yu, Ma Qianli, Liang Rongchang, Zhao Xuemin. The effect of flow velocity on the growth of different planktonic algae [J]. Ecological Science, 2018, 37(06): 75-82.

[18] Zhao Ying. Experimental study on the effect of hydrological and meteorological factors on the growth of algae [D]. Hohai University, 2006.

[19] Duan Dehui. The impact of acid rain on some organisms in the aquatic ecosystem[J]. Lake Science, 1993(01): 85-91.

[20] J. L. Stoddard, D. S. Jeffries, A. Lukewille, T. A. Clair, P. J. Dillon, C. T. Driscoll, M. Forsius, M. Johannessen, J. S. Kahl, J. H. Kellogg, A. Kemp, J. Mannio, D. T. Monteith, P. S. Murdoch,
S. Patrick, A. Rebsdorf, B. L. Skjelkvåle, M. P. Stainton, T. Traaen, H. van Dam, K. E. Webster, J. Wieting, A. Wilander. Regional trends in aquatic recovery from acidification in North America and Europe[J]. Nature: International weekly journal of science, 1999, 401(6753).

[21] Peng Jinliang, Yan Guoan, Shen Guoxing, Yan Xue, Liu Yongding. The impact of acid rain on aquatic ecosystems[J]. Chinese Journal of Hydrobiology, 2001(03):282-288.

[22] Ralph Smith. Limnology—Inland water ecosystems[J]. Journal of the North American Benthological Society, 2002, 21(2).

[23] Yuan Hezhong, Shen Ji, Liu Enfeng, Meng Xianghua, Wang Jianjun. Phosphorus release characteristics in the sediments of Meiliang Bay in Taihu Lake under simulated water pH control[J]. Journal of Lake Science, 2009, 21(05): 663-668.

[24] Emil Rydin. Potentially mobile phosphorus in Lake Erken sediment[J]. Water Research, 2000, 34(7).

[25] Shengrui Wang, Xiangcan Jin, Haichao Zhao, Fengchang Wu. Phosphorus fractions and its release in the sediments from the shallow lakes in the middle and lower reaches of Yangtze River area in China[J]. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 2005, 273(1).

[26] Yunlin Zhang, Kun Shi, Yongqiang Zhou, Xiaohan Liu, Boqiang Qin. Monitoring the river plume induced by heavy rainfall events in large, shallow, Lake Taihu using MODIS 250 m imagery. Remote Sensing of Environment, 2016, 173.

[27] Zhen Yang, Min Zhang, Xiaoli Shi, Fanxiang Kong, Ronghua Ma, Yang Yu. Nutrient reduction magnifies the impact of extreme weather on cyanobacterial bloom formation in large shallow Lake Taihu (China)[J]. Water Research, 2016, 103.