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Annual dynamics of water quality in a small urban landscape lake: a case study of Lake Wuzhou, China

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ABSTRACT

The aim of this study was to investigate the relationship between the water quality factors of Lake Wuzhou. This was achieved through an analysis of the annual dynamics of the water quality of Lake Wuzhou. This study also aimed at revealing the annual response mechanism of water factors, which not only includes the ecological theoretical significance, but also the extensive practical application potential for the management and evaluation of aquatic ecosystems in small water bodies. A total of 11 sampling points were chosen in Lake Wuzhou waters to collect sub-surface 2017, July 2017, September 2017 and November 2017 January 2018, and March 2018. After sample collection, pH, biochemical oxygen demand (BOD), chemical oxygen demand (COD), ammonia nitrogen (NH_3–N), total nitrogen (TN), total phosphorus (TP), nitrate–nitrogen (NO_3–N), and chlorophyll-a (Chl-a) were analyzed. The findings for the annual dynamics of water quality in Lake Wuzhou were as follows: (1) COD and BOD parameters were consistent except for those in March 2018 and May 2017 which were significantly lower than those for the other months; the annual dynamics findings for May 2017, September 2017 November, and January 2018 show an increasing trend. The results for TN and TP water quality parameters also show consistency for all the months except for those in January and March which are significantly lower than those in the other months. NH_3–N is significantly lower in March and September than those in the other months. The results for NO_3–N and Chl-a demonstrate high consistency for all the months except for those in November which were significantly higher than those in the other months while the results for May were significantly lower than those in other months. (2) BOD test measurements indicated that Lake Wuzhou water bodies are classified as class V water in the month of March 2018 and May 2017 but the results for BOD test measurements for all the other months indicated inferior class V water. The annual results for COD, NH_3–N, TN and TP of the water of Lake Wuzhou indicate an inferior class to class V water and this demonstrates that they are severely eutrophic water bodies. Carlson trophic state index was used to assess the nutritional status of water and the measurements led to the conclusion that Lake Wuzhou is severely eutrophic. (3) The correlation results of water quality factors of Lake Wuzhou waters were as follows: there is an extremely significant positive correlation between Chl-a and BOD, COD, TN, TP, NH_3–N, a significant negative correlation between pH and TN, TP, NO_3–N ($p < 0.05$), and an extremely significant negative correlation between NO_3–N and NH_3–N. In conclusion, Lake Wuzhou demonstrates a high presence of eutrophication which is driven by the accumulation of nutrients. To control the eutrophication, it is recommended that the density of reed communities should be increased while the density of lotus communities should be reduced.

Keywords: Landscape Lake; Small water bodies; Water quality; Lake Wuzhou

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1. Introduction

Eutrophication of water bodies has been identified as an environmental issue of global concern [1,2]. The cause and sensitivities of eutrophication differ in various water bodies including oceans, lakes, rivers, and reservoirs. Considering that, there is a close correlation with hydrology, hydrodynamics and food webs and it should be noted that most of these water bodies contain nutrient substances like nitrogen and phosphorus [1–3]. In China, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are the main indicators of water quality. Phytoplankton plays an important role in the aquatic ecosystem. As an indicator species, it is extremely sensitive to the pollutants in the water environment, which serves as an essential indicator reflecting the characteristics and quality of the water environment, and therefore it has wide application in monitoring and evaluation of the water environment [4,5]. Chlorophyll-a (Chl-a) is a critical component of phytoplankton [6]. The content of Chl-a in a water body is an important indicator for describing and classifying water body nutrient status and for studying the water habitat, therefore, playing an important role in the evaluation of eutrophication [7,8]. Researchers from all over the world have reported different correlation results between Chl-a and other water quality parameters such as nitrogen and phosphorus [9,10].

Presently, small water bodies including ponds, small lakes, low-level streams, ditches, and springs, form a major part of the world's freshwater environment, but most of them are excluded from water resources management planning activities and are rarely investigated [11]. Lake Wuzhou, which is located right ahead of the office building of Linyi Administrative Center, Shandong Province, China, is a famous sightseeing and recreational lake in Linyi City. This paper investigates the relationship between Chl-a and other water quality factors of Lake Wuzhou through analysis of the annual dynamic characteristics of waters of Lake Wuzhou determining the annual response mechanism of water factors, which not only carries ecological theoretical significance but also impacts on the extensive practical application potential for the management and evaluation of aquatic ecosystems in the small water bodies.

2. Materials and methods

2.1. Overview of the research basin

Lake Wuzhou, with geographical coordinates of 118.35°E, 35.10°N, has an area of 26 hm^2 and a water area of 13 hm^2. The average depth of the lake is 2 m. Belonging to a semi-closed urban shallow water body, Lake Wuzhou was put into use in July 2009. The water renewal and source mainly depend on the natural rainfall and artificial infusion and therefore there is limited environmental capacity and poor self-purification ability. When Lake Wuzhou was first built, the water was clear and sparkling, presenting a beautiful landscape. However, algal bloom with slight an odor nowadays often appears on the surface of Lake Wuzhou, and aquatic plants wither now and then, breeding mosquitoes and files. As an artificial lake, Lake Wuzhou supports a sensitive and fragile ecosystem at stake. The samples were collected during May (wet seasons), July (wet seasons), September (wet seasons), and November (dry seasons) in 2017, and January (dry seasons) and March (dry seasons) in 2018.

2.2. Water sample collection and laboratory procedures

In this survey, a total of 11 sampling points were set up in Lake Wuzhou, with one on the two shoulders and center of the heart-shaped lake in the north respectively, two at the east entrance, one in the west, three in the middle of the lake, and two in the southwest of the lake (Fig. 1). A 2.5 L clean plastic bucket was used to collect surface water samples (sampling depth 0.5 m) to be sent to the laboratory for water quality analysis, including pH, 5 d BOD, COD, total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH_3–N), NO_3–N, and Chl-a.

The pH was measured using a portable waterproof pH meter consisting of a glass electrode. BOD was determined by dilution and inoculation method using a 25 mL acid burette. COD was measured by the dichromate method using a 50 mL acid burette. NH_3–N and TP were measured with the help of Nessler reagent spectrophotometry and ammonium molybdate spectrophotometry using DR2008 visible spectrophotometer. TN was analyzed using a UV-1750 ultraviolet-visible spectrophotometer. NO_3–N was analyzed by ion chromatography using an ICS-90A ion chromatograph. Chl-content was quantified through acetone spectrophotometry.

2.3. Data analysis

Statistical analysis was performed on the acquired data using statistical package for social sciences (SPSS) software 19.0 Chinese version which includes statistical tools for computing independent sample *t*-test, one-way ANOVA, and correlation analysis.

3. Results

The pH results of Lake Wuzhou range from 7.18–8.27 throughout the year except for the high annual fluctuations

Fig. 1. Sampling sites in Lake Wuzhou.

in January, March and July during which the pH recorded was significantly higher than that of May, September, and November ($p < 0.01$) (Fig. 2a).

The COD test measurements of Lake Wuzhou ranged from 10.71–44.95 mg L^{-1} throughout the year except for, the high annual fluctuations in March and May during which the COD recorded was significantly lower than that in the other months. The COD results recorded in May, September, November, and January also exhibited an increasing trend ($p < 0.01$) (Fig. 2b).

The BOD results of Lake Wuzhou ranged from 33.00–17.91 mg L^{-1} throughout the year, except for high annual fluctuations in March and May during which the BOD recorded was significantly lower than that in the other months. The BOD results recorded in May, September, November, and January also exhibited an increasing trend ($p < 0.01$) (Fig. 2c).

The TN concentration of Lake Wuzhou was found to range from 7.97–20.43 mg L^{-1} throughout the year except for the high annual fluctuations observed in January and March during which the TN concentration recorded was significantly lower than that of the other months ($p < 0.01$) (Fig. 2d).

The TP concentration of Lake Wuzhou was found to range from 0.41–2.13 mg L^{-1} throughout the year except for the high annual fluctuations recorded in January and March during which the TP concentration recorded was significantly lower than that in the other months ($p < 0.01$) (Fig. 2e).

The NH_3–N concentration of Lake Wuzhou was found to range from 3.29–13.21 mg L^{-1} throughout the year except for the high fluctuation recorded in March and September during which the NH_3–N concentration recorded was significantly lower than that in the other months ($p < 0.01$) (Fig. 2f).

The NO_3–N concentration of Lake Wuzhou was found to range from 0.09–29.70 mg L^{-1} throughout the year except for the high annual fluctuations recorded in September and November during which the NO_3–N concentration recorded was significantly higher than that in the other months, while the NO_3–N concentration recorded in May was significantly lower than that in other months ($p < 0.01$) (Fig. 2g).

The level of Chl-a recorded from Lake Wuzhou was found to range from 45.79–318.79 μg L^{-1} throughout the year except for the high annual fluctuations in November during which the level of Chl-a recorded was found to be significantly higher than that in the other months while that recorded in May was significantly lower than that in the other months ($p < 0.01$) (Fig. 2h).

3.1. Water quality evaluation

The BOD, COD, NH_3–N, TN and TP test results were used to evaluate water quality of Lake Wuzhou according to China's Environmental Quality Standards for surface water.

As indicated by the BOD test measures, the water quality of Lake Wuzhou is barely class V in March and May and exhibits inferior class V water quality in the other months. As shown by the COD, NH_3–N, TN and TP results, the water quality of Lake Wuzhou is even worse throughout the year being inferior class V water quality and severely eutrophic.

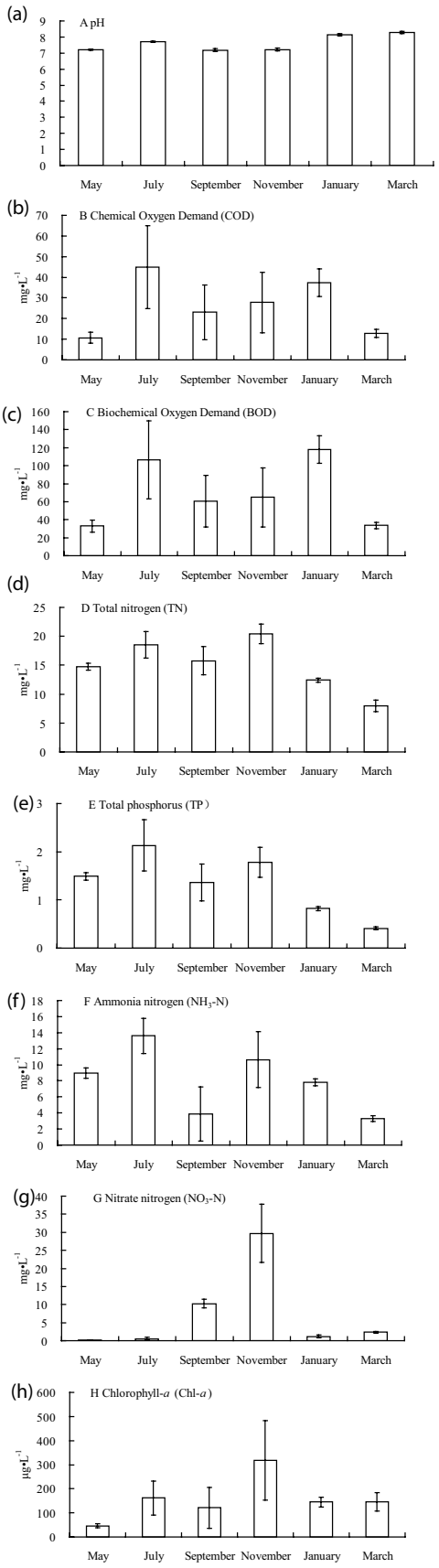

Fig. 2. Annual dynamics (±standard error) of water environmental factors in Lake Wuzhou (a) pH, (b) BOD, (c) COD, (d) TN, (e) TP, (f) NH_3–N, (g) NO_3–N, and (h) Chl-a.

The Carlson trophic state index (CTSI) [12] was used to assess the nutritional status of water and the results showed that: CTSI (Chl) = 80.14, CTSI (TP) = 107.92 indicating that the water quality of Lake Wuzhou is severely eutrophic.

3.2. Correlation of water environmental factors

For correlation results of water quality factors of Lake Wuzhou (Table 1), there is an extremely significant positive correlation between Chl-a and BOD, COD, TN, TP, NH_3–N concentrations, a significant negative correlation between pH and TN, TP, NO_3–N ($p < 0.05$) concentrations, and an extremely significant negative correlation between NO_3–N and NH_3–N concentrations. The water quality parameters of Lake Wuzhou are also related to precipitation and temperature (Fig. 3).

4. Discussion

Studies conducted on the water bodies of Wuliangsuhai [13] and Baiyangdian [14] in China show that lotus cultivation can significantly improve water quality by markedly inhibiting the growth of algae in water bodies. At present, in some parts of Lake Wuzhou waters, high-density lotuses and very low-density reeds are planted resulting in highly eutrophic water bodies. The findings of small water bodies in Lake Wuzhou are contrary to that of the two large and medium-sized water bodies of Wuliangsuhai [13] and Baiyangdian [14] in China. Similar to the conclusion made for these water bodies, the lotus can effectively increase BOD, COD, and Chl-a concentrations in Yihe River Urban Wetlands [15,16]. This may be because lotus density stimulates the hormesis effect on algae found in water bodies [1] while reeds can significantly lower BOD, COD, TN, NO_3, and Chl-a concentrations [15,16] and Lake Wuzhou happens to have high-density lotus. Studies on various eutrophic shallow lakes such as Barton Broad, in the United Kingdom [17], and Lake Tai, in China [18], indicate that a suitable nitrogen-phosphorus ratio will boost the growth and outbreak of phytoplankton blooms in a water body. Currently, Lake Wuzhou has a nitrogen-phosphorus ratio of 11.23, which indicates a suitable site for the growth and outbreak of phytoplankton. This leads to the conclusion that eutrophication in Lake Wuzhou, is driven by nutrient accumulation in form of a suitable nitrogen-phosphorus ratio. It is therefore advisable to increase the area and density of reed communities while reducing the density of lotus communities.

The summary of the annual dynamics of water quality factors of Lake Wuzhou waters are as follows: COD and BOD concentrations are consistent throughout the year except for, March and May during which the COD and BOD concentrations are significantly lower than those in the other months. An increasing trend in the concentration is also shown for May, September, November, and January. TN and TP concentrations are consistent throughout the year except for January and March during which the TN and TP concentrations are significantly lower than those in the other months. The concentration of NH_3–N is significantly lower in March and September than in the other months. NO_3–N and Chl-a concentrations are generally consistent throughout the year except for November during which the concentrations of NH_3–N is significantly higher than those in the other months and those in May are significantly lower than those in the other months. The content of Chl-a in Lake Wuzhou is higher in autumn and summer and lower in winter and spring. This observation is similar to

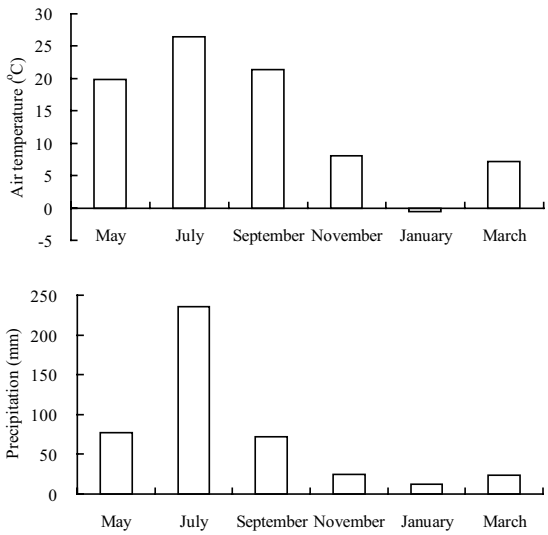

Fig. 3. Air temperature and precipitation near Lake Wuzhou.

Table 1
Correlation of environmental factors in Lake Wuzhou waters

	pH	COD	BOD	TN	TP	NH_3–N	NO_3–N	Chl-a
pH	1.000							
COD	–0.048	1.000						
BOD	–0.003	0.984**	1.000					
TN	–0.521**	0.687**	0.657**	1.000				
TP	–0.418**	0.789**	0.748**	0.917**	1.000			
NH_3–N	–0.213	0.699**	0.691**	0.808**	0.849**	1.000		
NO_3–N	–0.277*	–0.166	–0.203	0.110	–0.061	–0.335**	1.000	
Chl-a	–0.159	0.686**	0.678**	0.645**	0.664**	0.714**	–0.153	1.000

*$p < 0.05$; **$p < 0.01$

that of the Miyun Reservoir in China [19], but different from the lakes Michigan and Huron in the USA [20]. In particular, the content of Chl-a in Lake Wuzhou is the highest in autumn, which is contrary to that of Lake Vela in Portugal [21] which is the highest in spring. This could indicate that the pocket water bodies like Lake Wuzhou are more likely to be limited by water temperature and nutrients than by precipitation [22].

Based on our recommendations, Linyi Municipal government has constructed a water source pipeline for Lake Wuzhou. On December 3, 2019, the Lake Wuzhou water diversion pipeline project was completed. The water from Liuqing River now enters the water diversion pipeline through the water diversion gate and flows into Lake Wuzhou resulting in a continuous supply of clear water.

5. Conclusion

- From the annual dynamics of water quality evaluation of Lake Wuzhou, as shown by the BOD concentration, the water in Lake Wuzhou is barely classified as class V in March and May and is classified as inferior class V water in all the other months. As indicated by the COD, NH_3–N, TN and TP concentration, the water quality of Lake Wuzhou is of inferior class V indicating that it is severely eutrophic. The CTSI was used to evaluate the nutritional status of water and Lake Wuzhou was found to be severely eutrophic.
- The correlation results of the water quality factors of Lake Wuzhou waters are as follows: there is an extremely significant positive correlation between the Chl-a and BOD, COD, TN, TP, NH_3–N concentrations ($p < 0.01$), a significant negative correlation between the pH and TN, TP, NO_3–N concentrations ($p < 0.05$), and an extremely significant negative correlation between NO_3–N and NH_3–N concentrations.

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References

[1] M. Schaffner, H.P. Bader, R. Scheidegger, Modeling the contribution of point sources and nonpoint sources to Thachin River water pollution, Sci. Total Environ., 407 (2009) 4902–4915.
[2] H. Zhang, G.H. Huang, Assessment of non-point source pollution using a spatial multicriteria analysis approach, Ecol. Modell., 222 (2011) 313–321.
[3] D.L. Li, T. Zhang, T.Y. Xiao, J.B. Yu, H.Q. Wang, K.J. Chen, A.M. Liu, Z.J. Li, Phytoplankton's community structure and its relationships with environmental factors in an aquaculture lake, Datong Lake of China, Chin. J. Appl. Ecol., 23 (2012) 2107–2113.
[4] M.X. Zhao, L.M. Lei, B.P. Han, Seasonal change in phytoplankton communities in Tangxi Reservoir and the effecting factors, J. Trop. Subtrop. Bot., 13 (2005) 386–392.
[5] J.H. Xu, W.B. Pan, H.Y. Zhang, Studying on planktonicalgae and characteristics of water quality of some small and adlittoral artificial lake in the city zone, Ecol. Sci., 26 (2007) 36–40.
[6] Z. Wang, H. Zou, G.J. Yang, H.J. Zhang, Y. Zhuang, Spatial-temporal characteristics of chlorophyll-a and its relationship with environmental factors in Lake Taihu, J. Lake Sci., 26 (2014) 567–575.
[7] S.M. Tian, Y. Yang, Y.M. Qiao, W.X. He, J.H. Lin, D.Y. Wang, Temporal and spatial distribution of phytoplankton chlorophyll-a and its relationships with environmental factors in Dongjiang River, Pearl River basin, J. Lake Sci., 27 (2015) 31–37.
[8] H.C. Lv, F.E. Wang, Y.X. Chen, Z.M. Yu, Z.F. Fang, G.D. Zhou, Multianalysis between chlorophyll-a and environmental factors in Qiandao Lake water, Chin. J. Appl. Ecol., 14 (2003) 1347–1350.
[9] R.T. James, K. Havens, G.W. Zhu, B.Q. Qin, Comparative analysis of nutrients, chlorophyll and transparency in two large shallow lakes (Lake Taihu, P.R. China and Lake Okeechobee, USA), Hydrobiologia, 627 (2009) 211–231.
[10] M.J. Chen, J. Li, X. Dai, Y. Sun, F.Z. Chen, Effects of phosphorus and temperature on chlorophyll-a contents and cell sizes of *Scenedesmus obliuus* and *Microcystis aeruginosa*, Limnology, 12 (2011) 187–192.
[11] J.S. Biggs, M. von Fumetti, M. Kelly-Quinn, The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers, Hydrobiologia, 793 (2017) 3–39.
[12] R.E. Carlson, A trophic state index for lakes, Limnol. Oceanogr., 22 (1977) 361–369.
[13] X. Li, X.Q. Xu, M.M. Gou, Study on the influence of lotus planting in Wuliangsu of inner Mongolia on water environment, J. Environ. Health, 35 (2018) 457–459.
[14] X.W. Liu, J. Liu, N and P dynamic of *Phragmites australis* and *Typha angustata* litter in Dawen River wetland during the decomposition, J. Qingdao Agric. Univ., (Natural Science), 29 (2012) 289–293.
[15] X. Li, Y. Gao, Influence of the island with grass and the island with trees to water quality in Yihe River, China, Desal. Water Treat., 121 (2018) 186–190.
[16] S.Z. Xu, Y.X. Wang, Y.D. Wang, Y.J. Zhao, Y. Gao, Seasonal influence of reed (*Phragmites australis*) and lotus (*Nelumbo nucifera*) on urban wetland of Yi River, Appl. Ecol. Environ. Res., 7 (2019) 7891–7900.
[17] S.S.S. Lau, S.N. Lane, Biological and chemical factors influencing shallow lake eutrophication, a long-term study, Sci. Total Environ., 288 (2002) 167–181.
[18] X. Liu, X.H. Lu, Y.W. Chen, The effects of temperature and nutrient ratios on *Microcystis* blooms in Lake Taihu, China: an 11-year investigation, Harmful Algae, 10 (2011) 337–343.
[19] G.S. Du, J.T. Wang, D.W. Wu, P. Zhao, W.H. Zhang, Y.Y. Gang, Structure and density of the phytoplankton community of Miyun Reservoir, Chin. J. Plant Ecol., 25 (2001) 501–504.
[20] M.H. Stadig, P.D. Collingsworth, B.M. Lesht, T.O. Höök, Spatially heterogeneous trends in nearshore and offshore chlorophyll-a concentrations in lakes Michigan and Huron (1998–2013), Freshwater Biol., 65 (2020) 366–378.
[21] N. Abrantes, S. Antunes, M. Pereira, F. Gonçalves, Seasonal succession of cladocerans and phytoplankton and their interactions in a Shallow Eutrophic lake (lake Vela, Portugal), Acta Oecologica, 29 (2006) 54–64.
[22] J.C. Ho, A.M. Michalak, Exploring temperature and precipitation impacts on harmful algal blooms across continental U.S. lakes, Limnol. Oceanogr., 9999 (2019) 1–18.