WATER QUALITY CHANGES AND EVALUATION AFTER DREDGING OF WUZHOU LAKE, CHINA

XUE, C.[1] – GAO, Y.[2,3*] – WANG, Y.[1] – ZHOU, J.[1]

[1]School of Life Sciences, Qufu Normal University, Jining 273165, China
(e-mail: xuebhc1001@163.com; yingwangqf@qfnu.edu.cn; jingzhou-2004@163.com)

[2]Shandong Provincial Key Laboratory of Water and Soil Conservation and Environmental Protection, College of Resources and Environment, Linyi University, Linyi 276005, China

[3]Linyi Scientific Exploration Laboratory, Linyi 276037, China

**Corresponding author*
e-mail: 13589652495@163.com

(Received 5th Feb 2025; accepted 14th Apr 2025)

Abstract. Eutrophication caused by nutrient accumulation is a critical issue for small water bodies, yet the long-term effectiveness of dredging as a remediation strategy is not fully understood. This study evaluates water quality changes in Wuzhou Lake, China, over a 1.5-year period following dredging, to assess its short- to medium-term impacts on mitigating eutrophication. Water samples were collected from six sites before dredging (June 2021), after dredging (June 2022), and 1.5 years later (October 2023). Key water quality parameters, including pH, total phosphorus (TP), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), ammonia nitrogen (NH_3-N), nitrate, and chlorophyll-a (Chla), were analyzed. Results showed significant reductions in TP, Chla, TN, and NH_3-N levels, while nitrate levels increased. Post-dredging, NH_3-N improved to Class II water standards, and Chla shifted from eutrophic to mesotrophic conditions. After 1.5 years, BOD and COD improved to Class IV and III, respectively, while TP declined Class V. These findings confirm short-term effectiveness of dredging in reducing nutrient pollution, with significant improvements observed between June 2021 and June 2022. However, the limited changes between June 2022 and October 2023 suggest that other factors, such as water stock changes, may also influence water quality. Complementary measures, such as expanding reed vegetation and reducing lotus density, are needed to ensure long-term ecosystem sustainability.

Keywords: *water quality improvement, sediment dredging, eutrophication mitigation, urban lake restoration, nutrient dynamics*

Introduction

Eutrophication of water bodies is a globally pressing environmental issue that has gained increasing attention from researchers and environmental policymakers alike (Schaffner et al., 2010; Zhang and Huang, 2011; du Plessis, 2022; Yang et al., 2025). This process, which results from the excessive accumulation of nutrients, especially nitrogen (N) and phosphorus (P), leads to rapid growth of algae and aquatic plants, which can severely disrupt aquatic ecosystems (Akinnawo, 2023). The sensitivity and causes of eutrophication vary across different types of water bodies, including oceans, lakes, rivers, and reservoirs, but are typically constrained by these key nutrients (Maúre et al., 2021). Hydrological factors, such as water flow and exchange rates, hydrodynamic conditions, and interactions within the aquatic food web, also play critical roles in regulating nutrient levels and, by extension, eutrophication (Soro et al., 2023; Zhang et al., 2024). A commonly used indicator for assessing eutrophication in water bodies is chlorophyll-a (Chla), a key pigment in phytoplankton, which reflects the biomass of algae present in the water. Monitoring Chla concentrations provides

DOI: http://dx.doi.org/10.15666/aeer/2303_56435655

important insights into the trophic state of aquatic systems (Li et al., 2012) and serves as a fundamental metric for evaluating water quality and the health of aquatic habitats (Wang et al., 2014; Tian et al., 2015). As the abundance of phytoplankton increases due to nutrient overloading, Chla levels rise, signaling that a water body may be experiencing eutrophication. Thus, it plays a vital role in categorizing and describing the nutritional status of water bodies and is frequently employed in studies related to aquatic ecosystems (Lu et al., 2003; Liu et al., 2022).

While much of the research on eutrophication has focused on larger water bodies such as lakes and rivers, small water bodies—such as ponds, low-order streams, ditches, and springs—also represent a critical component of the global freshwater system. Despite their abundance, these small water bodies are often neglected in water resource management plans and scientific studies, making them a critical yet underexplored area in the context of eutrophication and freshwater conservation (Biggs et al., 2017). These small systems can be particularly vulnerable to nutrient overload due to their limited water exchange and smaller catchment areas, and they play significant roles in local hydrological cycles, biodiversity, and even global biogeochemical processes. Small lakes constitute common features in urban landscapes (Waajen et al., 2019; Singh and Yadav, 2025), frequently experiencing pronounced eutrophication impacts (Brönmark and Hansson, 2002) that drive phytoplankton bloom proliferation (Schindler et al., 2008).

An example of the consequences of eutrophication and sediment accumulation in a small water body can be observed in Wuzhou Lake, located in front of the administrative center office building in Linyi City, Shandong Province, China. Wuzhou Lake is a popular destination for sightseeing and recreational activities, but over time, its water quality has declined due to the unchecked growth and decay of aquatic plants, coupled with sediment deposition from upstream sources (Gao and Zhao, 2020). The lake’s weak water mobility has exacerbated these issues, leading to significant sediment accumulation at the bottom of the lake, with depths ranging from 30 cm to over 1.5 m in certain areas. It is estimated that approximately 45,000 m^3 of sediment has accumulated in Wuzhou Lake, creating a potential risk not only for water quality but also for flood safety in the surrounding area (Zhang et al., 2010). The accumulation of sediment can trap nutrients, further contributing to eutrophication and posing a challenge for water management and conservation efforts (Zhang et al., 2010).

Remediation of hypereutrophic lakes presents significant challenges, where sediment dredging emerges as a potential solution through removal of organic pollutant-enriched surface sediments, particularly phosphorus loading from benthic deposits (Gulati and van Donk, 2002; Jing et al., 2013; Liu et al., 2015; Fang et al., 2016). However, this intervention may compromise water column nitrogen removal capacity for several years post-dredging (Jing et al., 2013), thereby elevating aqueous N:P ratios and altering phytoplankton community structure and biomass dynamics (Jing et al., 2013). From December 2021 to March 2022, Wuzhou Lake underwent its first comprehensive dredging operation to address these concerns.

This study aims to address these gaps by conducting a comprehensive analysis of the long-term effects of dredging on the water quality of Wuzhou Lake, a small artificial lake in China, 1.5 years after dredging. Key water quality parameters, including biochemical oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH_3-N), and chlorophyll-a (Chla), are evaluated over time to assess changes and trends. By investigating the temporal dynamics of these indicators, the study provides novel insights into the long-term sustainability of dredging as a remediation technique for eutrophication in small water bodies. Furthermore, the findings contribute to the literature by highlighting the necessity of integrating dredging with preventive measures, such as nutrient input control and ecological restoration, for effective water management.

Materials and methods

Water sample collection and laboratory procedures

The Wuzhou Lake water system, as an important water system in Linyi City, Shandong Province, China, has experienced poor water quality in recent years due to issues such as improper connection of rainwater and sewage systems and a lack of water replenishment, leading to sewage discharge into the river channels. From December 2021 to March 2022, the Linyi Municipal Government has implemented dredging operations for Wuzhou Lake as a key measure to improve the water quality of the Wuzhou Lake system. The dredging process involves first pumping out all the water and temporarily storing it. Then, excavators and bulldozers are used to remove 50 cm of sediment from the lakebed. After several weeks of drying up, Wuzhou Lake regained water and settled in April 2022. To ensure the robustness of the experimental design, three key time intervals were selected for sampling: before dredging (June 2021), immediately after dredging (June 2022), and 1.5 years post-dredging (October 2023). This time frame was chosen to capture both short-term and medium-term changes in water quality following dredging, providing a comprehensive view of the intervention’s effects. Water samples were collected using 2.5 L clean plastic buckets from the surface layer and sent to the laboratory for water quality analysis. Parameters tested included pH, total phosphorus, biochemical oxygen demand, chemical oxygen demand, total nitrogen, ammonia nitrogen, nitrate, and chlorophyll-a content.

To minimize experimental error, all sampling and analytical procedures were conducted in triplicate, and strict quality control protocols were followed throughout. Calibration of instruments, such as the pH meter and spectrophotometer, was performed before each measurement session using standard solutions. Additionally, laboratory blanks and duplicates were included to ensure the accuracy and reliability of the results.

Wuzhou Lake is located at 118°35′E and 35°10′N, covering an area of 26 ha, with 13 ha of it being water. This semi-enclosed shallow water body, situated in an urban area, is a small artificial lake that has been in use since July 2009. The primary sources of water renewal for the lake are natural rainfall and artificial irrigation. However, its environmental capacity is limited, and it has poor self-purification abilities. There are six sampling points within the lake (*Fig. 1*): two at the shoulders of the northern heart-shaped water body, one each to the east and west, and one each to the south and southwest. Water samples were collected at three time points: before dredging (June 2021), immediately after dredging (June 2022), and 1.5 years post-dredging (October 2023). Surface water samples were gathered using 2.5 L clean plastic buckets and analyzed in the laboratory. The water quality parameters were tested using standard methods. pH was measured using a portable pH meter (GB/T 6920-1986, Model: pH-100, Manufacturer: Hanna Instruments). Total phosphorus (TP) was determined by the molybdenum blue spectrophotometric method after acid digestion (GB/T 11893-1989) using a UV-Vis spectrophotometer (Model: UV-1800, Manufacturer: Shimadzu). Biochemical oxygen demand (BOD) was measured using the 5-day incubation method

(BOD5) (GB/T 7488-1987) with a BOD meter (Model: BOD Trak II, Manufacturer: Hach), while chemical oxygen demand (COD) was analyzed by the dichromate oxidation method (HJ 828-2017) using a COD reactor and spectrophotometer (Model: DRB200 and DR6000, Manufacturer: Hach). Total nitrogen (TN) was quantified using alkaline persulfate digestion followed by UV spectrophotometry (GB/T 11894-1989) with a UV-Vis spectrophotometer (Model: UV-1800, Manufacturer: Shimadzu). Ammonia nitrogen (NH_3-N) was determined using the Nessler reagent spectrophotometric method (HJ 535-2009) with a UV-Vis spectrophotometer (Model: UV-1800, Manufacturer: Shimadzu), and nitrate nitrogen (NO_3^-) was analyzed by UV spectrophotometry (GB/T 7480-1987) using a UV-Vis spectrophotometer (Model: UV-1800, Manufacturer: Shimadzu). Chlorophyll-a (Chl-a) content was measured through acetone extraction followed by spectrophotometric analysis (HJ 897-2017) using a UV-Vis spectrophotometer (Model: UV-1800, Manufacturer: Shimadzu).

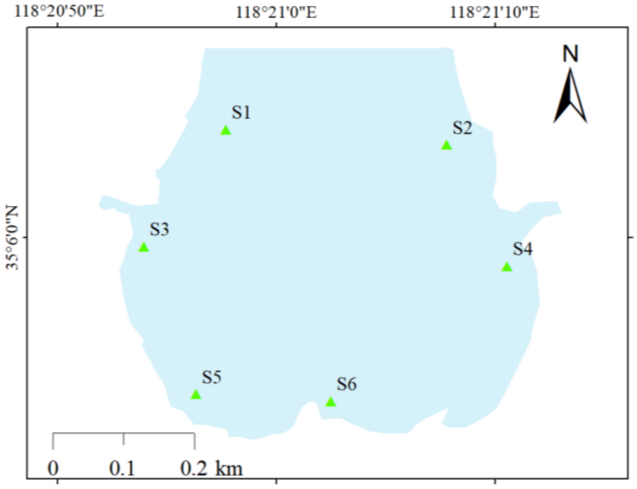

Figure 1. *The green triangles are the sampling points within the Wuzhou Lake*

Data analysis

The differences in water quality parameters before dredging, after dredging, and 1.5 years after dredging were analyzed using one-way ANOVA in SPSS software, and tested using the Tukey test. This statistical approach was chosen for its robustness in identifying significant differences between groups across multiple time points. The correlation between different water quality parameters was analyzed using SPSS software, applying Pearson correlation analysis. To further validate the findings, all statistical analyses were conducted with a significance level of $p < 0.05$, and results were cross-checked by an independent analyst to minimize bias.

Results

Changes in water quality factors after 1.5 years of dredging

Eight water quality factors showed varying degrees of change 1.5 years after dredging (*Fig. 2*). BOD, pH, and COD decreased slightly. TP and Chla content decreased significantly ($p < 0.05$), while NH_3, and TN decreased very significantly ($p < 0.001$). Only nitrate content increased very significantly ($p < 0.001$).

DOI: http://dx.doi.org/10.15666/aeer/2303_56435655

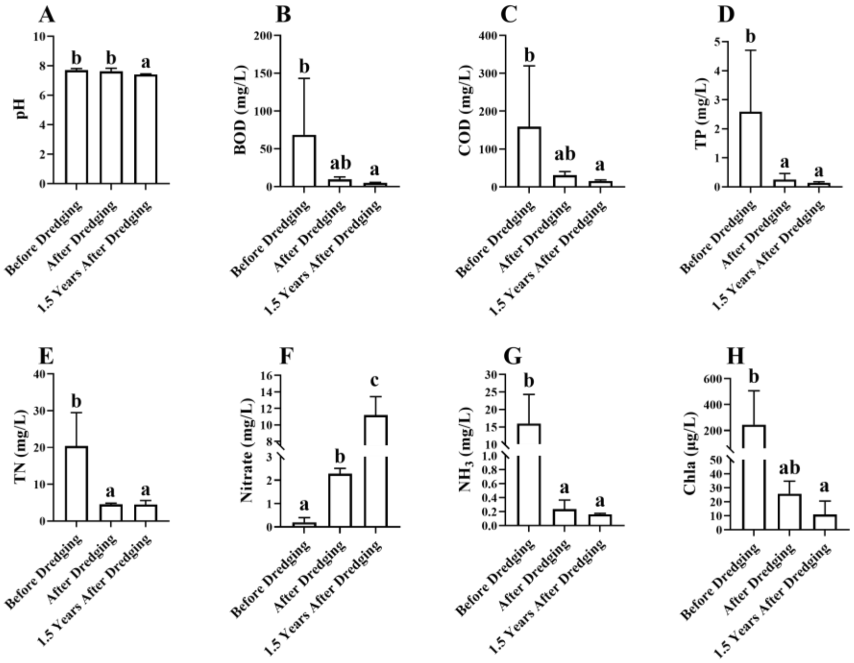

***Figure 2.** Changes in water environment factors*

Total phosphorus (TP), Biochemical oxygen demand (BOD), Chemical oxygen demand (COD), Total nitrogen (TN), Ammonia nitrogen (NH_3), Nitrate, and chlorophyll-a (Chla). Different letters indicate significant differences among the three sample groups, with $p < 0.05$.

Water quality evaluation after 1.5 years of dredging

Based on the surface water environmental quality standards (GB 3838-2002), single indicators for BOD, COD, TN, TP, and NH_3 were used to evaluate the water quality of Wuzhou Lake post-dredging, after dredging and 1.5 years after dredging (*Table 1*). Post-dredging, NH_3 indicators were Class II water, BOD and COD indicators were Class V water, and TN and TP indicators were worse than Class V water. Using the Chla indicator, the water body was evaluated as eutrophic. After dredging, NH_3 indicators were Class II water, BOD and COD indicators were Class V water, and TN and TP indicators were worse than Class V water. Using the Chla indicator, the water body improved to mesotrophic conditions. 1.5 years after dredging, BOD, COD, and TP indicators improved to Class IV, Class III, and Class V water, respectively. TN and NH_3 indicators remained stable, and the Chla indicator stayed mesotrophic conditions.

The significant reductions in TP and TN levels observed after dredging are primarily attributed to the removal of nutrient-rich sediments. While flora and fauna dynamics (e.g., lotus and reed populations) could influence nutrient cycling, our sampling timeline (June 2021–October 2023) did not align with significant vegetation management interventions. During this period, no active measures to alter plant density (e.g., lotus removal or reed expansion) were implemented, as these were proposed for future restoration phases (see “Recommendations”). Thus, the immediate post-dredging improvements (June 2022) are most plausibly linked to sediment removal rather than biotic factors. The dilution effect of water stock refreshment may have contributed, but

DOI: http://dx.doi.org/10.15666/aeer/2303_56435655

sediment excavation remains the dominant mechanism. Similarly, the increase in nitrate (NO_3^-) concentrations could be linked to enhanced nitrification processes driven by increased oxygen levels resulting from water stock refreshment.

Table 1. *Water quality of Wuzhou Lake 1.5 years after dredging*

Indicator	Before-dredging	After dredging	1.5 years after dredging	Trend
Biochemical oxygen demand	Class V water	Class V water	Class IV water	Improved
Chemical oxygen demand	Class V water	Class V water	Class III water	Improved
Total nitrogen	Worse than class V water	Worse than class V water	Worse than class V water	Stable
Total phosphorus	Worse than class V water	Worse than class V water	Class V water	Improved
Ammonia nitrogen	Class II water	Class II water	Class II water	Stable
Chlorophyll-a	Eutrophic	Mesotrophic	Mesotrophic	Improved

Correlation of environmental factors in Wuzhou Lake

The correlation analysis was performed on water quality parameters measured at three time points: before dredging (June 2021), after dredging (June 2022), and 1.5 years post-dredging (October 2023) (*Table 2*). To assess how dredging modified these correlations, we analyzed parameter relationships separately for each time period. To assess how dredging modified these correlations, we analyzed parameter relationships separately for each time period. Our results showed that, before dredging, TP exhibited a strong positive correlation with TN (r = **, $p < 0.01$) and Chla (r = **, $p < 0.05$), indicating that phosphorus availability was a major driver of algal biomass. However, after dredging, the correlation between TP and Chla weakened (r = **, $p > 0.05$), suggesting a shift in nutrient dynamics likely due to sediment removal and reduced internal loading. Similarly, the correlation between NH_3 and Chla, which was significant before dredging, became non-significant post-dredging. One notable observation was the increase in nitrate (NO_3^-) concentrations post-dredging and its strengthened correlation with TN and COD, indicating enhanced nitrification processes. This suggests that dredging not only removed nutrient-rich sediments but also altered nitrogen cycling pathways by increasing oxygenation. These findings confirm that while general relationships between parameters remain consistent with known environmental processes, dredging-induced changes in sediment composition and water chemistry modified specific interactions, particularly those related to nitrogen transformation and algal growth.

Table 2. *Correlation of environmental factors in Wuzhou Lake*

	pH	TP	BOD	COD	TN	NH_3	Nitrate	Chla
pH	1.000							
TP	0.356	1.000						
BOD	0.366	0.999**	1.000					
COD	0.394	0.950**	0.953**	1.000				
TN	0.451*	0.901**	0.908**	0.968**	1.000			
NH_3	0.466*	0.891**	0.897**	0.966**	0.995**	1.000		
Nitrate	0.358	0.976**	0.978**	0.980**	0.926**	0.919**	1.000	
Chla	-0.669**	-0.388	-0.407	-0.452*	-0.512*	-0.531*	-0.399	1.000

*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$. Notably, correlations between water quality parameters (e.g., TP, TN, Chla) and vegetation indices (e.g., plant biomass) were not analyzed, as vegetation data were not systematically collected. However, the absence of active vegetation management during the study period suggests that flora changes were minimal and unlikely to explain the abrupt post-dredging improvements

Discussion

Changes in water quality factors

Eight key water quality factors in Wuzhou Lake exhibited noticeable changes 1.5 years after the lake underwent dredging, with some parameters improving more significantly than others. Among the observed changes, the levels of pH, biochemical oxygen demand (BOD), and chemical oxygen demand (COD) decreased slightly, while the total phosphorus (TP) and chlorophyll-a (Chla) content dropped more significantly. A particularly striking result was the substantial reduction in ammonia (NH_3) and total nitrogen (TN) levels, whereas nitrate content showed a very significant increase. These findings are consistent with previous research studies (Wan et al., 2020; Zhang et al., 2010), but expand upon existing literature by providing longer-term insights into post-dredging nutrient dynamics, highlighting the importance of sustained reductions in TN and TP.

Nitrogen (N) and phosphorus (P) are well-known as limiting nutrients in freshwater ecosystems, especially those experiencing eutrophication (Zhang et al., 2013). In nutrient-rich environments, the presence of excess nitrogen and phosphorus drives algal blooms and other symptoms of eutrophication. The observed reductions in TN and TP likely stem from the removal of nutrient-rich sediments during dredging, which directly impacts algal growth as evidenced by the decline in Chla levels. This suggests a cascading effect: dredging reduces sediment-bound nutrients, limiting algal biomass and subsequently improving water clarity and ecosystem stability (Zhang et al., 2021). In Wuzhou Lake, the observed decrease in BOD and COD levels, albeit slight, suggests that dredging has had a positive effect in mitigating organic pollution.

However, the observed increase in nitrate content indicates a shift in nitrogen cycling post-dredging, potentially driven by enhanced nitrification processes due to improved oxygen availability in the water column. This highlights the complex ecological mechanisms underlying nutrient dynamics and underscores the need for adaptive management strategies.

The significant reduction in TN and TP concentrations between June 2021 and June 2022 suggests that dredging effectively removed nutrient-rich sediments, contributing to the mitigation of eutrophication. However, the lack of significant changes between June 2022 and October 2023 may indicate that other factors, such as water stock changes or seasonal variations, also played a role in influencing water quality. Further studies are needed to disentangle the effects of dredging from other environmental factors. This reduction is particularly important as it directly impacts algal growth, as supported by the simultaneous decrease in Chla levels, which is often used as an indicator of algal biomass (Lewis et al., 2001). The decline in Chla content observed in this study suggests that algal populations were reduced post-dredging, contributing to improved water clarity and overall ecological health. These findings align with earlier studies that suggest dredging can effectively reduce the abundance and diversity of plankton bacterial communities by lowering TN and TP levels in the water (Wan et al., 2020).

It is important to consider the potential impact of water stock changes on the observed water quality parameters. The significant changes between June 2021 and June 2022 may be attributed to the combined effects of dredging and water stock changes, while the lack of significant changes between June 2022 and October 2023 could be influenced by seasonal variations in water flow and nutrient inputs. Future studies should incorporate detailed hydrological data to better understand the interplay between dredging and water stock changes in influencing water quality.

In terms of water quality classification, the study also evaluated the status of Wuzhou Lake after dredging. Post-dredging, the NH_3 indicator improved to Class II water, which is relatively high quality (Zhang et al., 2010). However, the BOD and COD indicators remained at Class V, indicating poorer water quality for these measures (Li and Gao, 2018). TN and TP indicators, which are critical in understanding nutrient pollution, were still classified as worse than Class V, highlighting the persistent challenge of nutrient control (Zhang et al., 2013). Nevertheless, the Chla indicator, which evaluates the trophic state of the water, showed a shift from eutrophic to mesotrophic conditions 1.5 years after dredging, suggesting an overall improvement in water quality and ecosystem stability (Wan et al., 2020).

Following these results, the evaluation indicated further improvements in water quality for several key indicators. BOD and COD levels improved to Class IV and Class III water, respectively, while TP levels improved to Class V (Zhang et al., 2010). These improvements align with earlier findings but also reveal that while dredging effectively reduces immediate nutrient loads, complementary strategies are necessary to maintain longer-term gains, particularly for TN and NH_3 indicators (Zhang et al., 2013). Despite the promising results, this study has limitations. Seasonal variations in water quality were not accounted for, which could influence nutrient dynamics and algal growth patterns. Additionally, potential errors in sample collection or laboratory analysis may have introduced variability into the results. Future studies should incorporate year-round monitoring and advanced modeling to address these uncertainties.

Overall, the results suggest that dredging is an effective method for mitigating the eutrophication of water bodies by removing nutrient-rich sediments, improving water quality, and reducing algal blooms (Wan et al., 2020). However, while it offers significant improvements, it may need to be supplemented with other water management strategies to address persistent nutrient pollution challenges (Li and Gao, 2018).

Potential inducing factors of water quality changes

The observed improvements in water quality following dredging may not solely be attributed to the removal of nutrient-rich sediments. The complete water stock refreshment, which involved pumping out and refilling the lake, could have independently contributed to these changes. Water stock refreshment can significantly alter the nutrient cycle between water and sediment by diluting nutrient concentrations in the water column and increasing dissolved oxygen levels, which may enhance nitrification processes. This could explain the observed increase in nitrate (NO_3^-) concentrations post-dredging. Furthermore, the disturbance caused by water stock refreshment may have temporarily resuspended sediments, releasing nutrients into the water column before they were flushed out. These mechanisms suggest that water stock refreshment could have played a significant role in the short-term improvements in water quality, particularly in reducing TP and TN levels. Future studies should incorporate detailed hydrological data to better disentangle the effects of dredging and water stock refreshment on water quality dynamics.

Recommendations

Although dredging has been widely recognized as an effective method for improving water quality and reducing eutrophication in lakes, research has shown that its positive impact on the ecosystem may be short-lived. Studies suggest that dredging alone may only provide short-term improvements, typically lasting between one to two years, after which the lake may revert to its original eutrophic state if not combined with other restoration measures (Jing et al., 2013). Without additional ecological interventions, the nutrients that were removed during dredging could be reintroduced into the water through runoff, sediment resuspension, or other external sources, causing the lake's health to decline (Jing et al., 2013). In fact, in some cases, lakes may become even less healthy than before dredging, as the disturbance caused by dredging can disrupt the balance of the ecosystem and lead to unintended consequences such as reduced biodiversity and habitat degradation (Gao and Zhao, 2020). Studies have shown that dredging can lead to a temporary decline in water quality and the destruction of aquatic habitats, which may take years to recover fully (Liu et al., 2015).

This limitation highlights the need for an integrated approach to lake management, where dredging is combined with other ecological restoration techniques to ensure long-term improvements. One factor that needs particular attention in the case of Wuzhou Lake is the high density of lotus plants, which has been identified as a contributing factor to the lake's eutrophication (Gao and Zhao, 2020). While lotus plants are often valued for their aesthetic appeal and cultural significance, their high density can negatively impact water quality by increasing levels of biochemical oxygen demand (BOD), chemical oxygen demand (COD), and chlorophyll-a (Chla), all of which are indicators of organic pollution and algal biomass (Li and Gao, 2018; Xu et al., 2019). This is likely due to the lotus plants creating a hormesis effect in the lake, stimulating the growth of algae and further contributing to nutrient enrichment in the water. It is suggested that future studies incorporate a detailed quantitative assessment of the ecological roles played by Phragmites australis (reed) and Nelumbo nucifera (lotus). This could involve evaluating their impacts on nutrient cycling, sediment stabilization, and biodiversity support, as well as their influence on water quality. Such an analysis would provide a scientific basis for optimizing vegetation management strategies to improve the lake's ecological health.

In contrast, other studies have shown that reed plants have the opposite effect. Reeds, commonly used in ecological restoration projects, have been found to reduce concentrations of BOD, COD, and Chla in water bodies, making them a valuable tool for improving water quality in eutrophic lakes (Li and Gao, 2018). The difference between lotus and reed plants in terms of their impact on water quality can be attributed to their varying ecological functions. Lotus plants may create a dense canopy over the water, reducing light penetration and contributing to the accumulation of organic matter and nutrients (Li and Gao, 2018). This dense canopy can limit the photosynthesis of submerged vegetation, leading to further eutrophication. In contrast, reed plants promote water flow and aeration, which can help reduce the buildup of organic matter and improve overall water quality by enhancing oxygen exchange and filtering out nutrients (Xu et al., 2019). Reeds are often used in constructed wetlands due to their ability to mitigate nutrient loading and maintain a balanced aquatic environment (Zhou et al., 2024).

Given these findings, it is recommended that efforts to restore Wuzhou Lake should include increasing the area and density of reed communities while simultaneously reducing the density of lotus plants. By promoting the growth of reed plants, the lake can benefit from their ability to filter out pollutants and reduce nutrient concentrations, leading to a more balanced and healthier ecosystem (Xu et al., 2019). Reeds are highly effective in nutrient uptake, especially for nitrogen and phosphorus, making them a vital component in mitigating eutrophication (Zhou et al., 2024). At the same time, controlling the spread of lotus plants will help mitigate their contribution to eutrophication by reducing the accumulation of organic matter and preventing the excessive shading of submerged vegetation (Gao and Zhao, 2020). This approach will allow for a more sustainable long-term restoration of Wuzhou Lake, supporting both water quality improvements and biodiversity recovery.

A general consensus exists across aquatic system types that algal growth limitation is determined by both nitrogen (N) and phosphorus (P) concentrations and their N:P ratio rather than either nutrient alone (Guildford and Hecky, 2000; Paerl et al., 2011, 2016; Tong et al., 2018). To predict nutrient limitation patterns, freshwater ecologists frequently employ the theoretical framework positing a critical N:P supply ratio that optimizes primary producer growth (Schanz and Juon, 1983; Elser et al., 2007; Liu et al., 2020). Derived from Liebig's Law of the Minimum, this paradigm suggests algal growth in aquatic ecosystems becomes N-limited when the aqueous N:P ratio falls below 16 (molar basis), while P-limitation occurs when ratios exceed 16 (Keck and Lepori, 2012; Liu et al., 2020). Alternative formulations using the TN:TP mass ratio propose N-limitation thresholds at TN:TP < 9 and P-limitation thresholds at TN:TP > 23 (Guildford and Hecky, 2000), with some studies establishing a nitrogen limitation threshold at TN:TP < 25 (Gal et al., 2009). Our investigation revealed persistent elevation of the N:P ratio in Wuzhou Lake, transitioning from pre-dredging N-limitation to post-dredging P-limitation status, which persisted 1.5 years after sediment removal (see *Table 3*).

Table 3. *N:P in Wuzhou Lake*

	N:P	**Restrictive**
Before-dredging (2021)	9.58	N restrictive
After dredging (2022)	26.92	P restrictive
1.5 years after dredging (2023)	32.31	P restrictive

To mitigate potential phosphorus re-release, sediment capping with clean sand has been proposed as a promising containment strategy (Pan et al., 2012). In conclusion, while dredging is an important first step in addressing eutrophication, it should not be viewed as a standalone solution. A comprehensive, multi-faceted approach that includes the management of aquatic plant communities—particularly the reduction of lotus density and the expansion of reed populations—can help ensure the long-term health and ecological balance of Wuzhou Lake.

Conclusion

Our study demonstrates that dredging effectively mitigates eutrophication in small water bodies over a 1.5-year period, as evidenced by significant improvements in key water quality indicators. However, the observed water quality changes may also be influenced by water stock refreshment, highlighting the need for future studies to monitor both dredging and water stock refreshment separately to better understand their individual and combined impacts. Additionally, the study period is too short to confirm long-term impacts, and we recommend expanding the monitoring period in future research to assess the sustained effects of dredging. Evaluating the effectiveness of complementary measures, such as expanding reed communities and reducing lotus density, should also be prioritized. Continuous ecological monitoring and adaptive management strategies are essential for ensuring the long-term health and sustainability of Wuzhou Lake and similar water bodies.

Acknowledgments. Supported by Shandong Provincial Key Laboratory of Water and Soil Conservation and Environmental Protection (No. STKF202307), Shandong Provincial Key Laboratory of Water and Soil Conservation and Environmental Protection, Linyi University, China.

REFERENCES

[1] Akinnawo, S. O. (2023): Eutrophication: causes, consequences, physical, chemical and biological techniques for mitigation strategies. – Environmental Challenges 12: 100733. https://doi.org/10.1016/j.envc.2023.100733.
[2] Biggs, J., von Fumetti, S., Kelly-Quinn, M. (2017): The importance of small waterbodies for biodiversity and ecosystem services: implications for policy makers. – Hydrobiologia 793: 3-39.
[3] Brönmark, C., Hansson, L. A. (2002): Environmental issues in lakes and ponds: current state and perspectives. – Environmental Conservation 29(3): 290-307.
[4] du Plessis, A. (2022): Persistent degradation: global water quality challenges and required actions. – One Earth 5(2): 129-131.
[5] Elser, J. J., Bracken, M. E. S., Cleland, E. E., Gruner, D. S., Harpole, W. S., Hillebrand, H., Ngai, J. T., Seabloom, E. W., Shurin, J. B., Smith, J. E. (2007): Global analysis of nitrogen and phosphorus limitation of primary producers in freshwater, marine and terrestrial ecosystems. – Ecology Letters 10(12): 1135-1142.
[6] Fang, T., Bao, S., Sima, X., Jiang, H., Zhu, W., Tang, W. (2016): Study on the application of integrated eco-engineering in purifying eutrophic river waters. – Ecological Engineering 94: 320-328.
[7] Gal, G., Hipsey, M. R., Parparov, A., Wagner, U., Makler, V., Zohary, T. (2009): Implementation of ecological modeling as an effective management and investigation tool: Lake Kinneret as a case study. – Ecological Modelling 220(13-14): 1697-1718.
[8] Gao, Y., Zhao, Y. (2020): Annual dynamics of water quality in a small urban landscape lake: a case study of lake Wuzhou, China. – Desalination and Water Treatment 202: 264-268.
[9] Guildford, S. J., Hecky, R. E. (2000): Total nitrogen, total phosphorus, and nutrient limitation in lakes and oceans: Is there a common relationship? – Limnology and Oceanography 45: 1213-1223.
[10] Gulati, R. D., van Donk, E. (2002): Lakes in the Netherlands, their origin, eutrophication and restoration: state-of-the-art review. – Hydrobiologia 478: 73-106.
[11] Jing, L., Wu, C., Liu, J., Wang, H., Ao, H. (2013): The effects of dredging on nitrogen balance in sediment-water microcosms and implications to dredging projects. – Ecological Engineering 52: 167-174.
[12] Keck, F., Lepori, F. (2012): Can we predict nutrient limitation in streams and rivers? – Freshwater Biology 57(7): 1410-1421.
[13] Lewis, M. A., Weber, D. E., Stanley, R. S., Moore, J. C. (2001): Dredging impact on an urbanized Florida bayou: effects on benthos and algal-periphyton. – Environmental Pollution 115(2): 161-171.
[14] Li, D., Zhang, T., Xiao, T., Yu, J., Wang, H., Chen, K., Liu, A., Li, Z. (2012): Phytoplankton's community structure and its relationships with environmental factors in

an aquaculture lake, Datong Lake of China. – Chinese Journal of Applied Ecology 23(8): 2107-2113. https://www.cjae.net/EN/Y2012/V23/I08/2107.

[15] Li, X., Gao, Y. (2018): Influence of the island with grass and the island with trees to water quality in Yihe River, China. – Desalination and Water Treatment 121: 186-190.

[16] Liu, C., Shen, Q., Zhou, Q., Fan, C., Shao, S. (2015): Precontrol of algae-induced black blooms through sediment dredging at appropriate depth in a typical eutrophic shallow lake. – Ecological Engineering 77: 139-145.

[17] Liu, J., Feng, Y., Zhang, Y., Liang, N., Wu, H., Liu, F. (2022): Allometric releases of nitrogen and phosphorus from sediments mediated by bacteria determines water eutrophication in coastal river basins of Bohai Bay. – Ecotoxicology and Environmental Safety 235: 113426. https://doi.org/10.1016/j.ecoenv.2022.113426.

[18] Liu, J., Wang, Y., Li, Y., Liu, X., Jiang, Y., Fu, Y., Jin, W., Wu, J. (2020): Ecosystem N:P stoichiometric ratios determine the catchment surface water N:P ratio through subsurface hydrological processes. – Catena 194: 104740. https://doi.org/10.1016/j.catena.2020.104740.

[19] Lu, H., Wang, F., Chen, Y., Yu, Z., Fang, Z., Zhou, G. (2003): Multianalysis between chlorophyll-a and environmental factors in Qiandao Lake water. – Chinese Journal of Applied Ecology 14(8): 1347-1350. https://www.cjae.net/EN/Y2003/V/I8/1347.

[20] Maúre, E. d. R., Terauchi, G., Ishizaka, J., Clinton, N., DeWitt, M. (2021): Globally consistent assessment of coastal eutrophication. – Nature Communications 12: 6142. https://doi.org/10.1038/s41467-021-26391-9

[21] Paerl, H. W., Xu, H., McCarthy, M. J., Zhu, G., Qin, B., Li, Y., Gardner, W. S. (2011): Controlling harmful cyanobacterial blooms in a hyper-eutrophic lake (Lake Taihu, China): the need for a dual nutrient (N & P) management strategy. – Water Research 45(5): 1973-1983.

[22] Paerl, H. W., Scott, J. T., McCarthy, M. J., Newell, S. E., Gardner, W. S., Havens, K. E., Hoffman, D. K., Wilhelm, S. W., Wurtsbaugh, W. A. (2016): It takes two to tango: when and where dual nutrient (N & P) reductions are needed to protect lakes and downstream ecosystems. – Environmental Science & Technology 50(20): 10805-10813.

[23] Pan, G., Dai, L., Li, L., He, L., Li, H., Bi, L., Gulati, R. (2012): Reducing the recruitment of sedimented algae and nutrient release into the overlying water using modified soil/sand flocculation-capping in eutrophic lakes. – Environmental Science & Technology 46(9): 5077-5084.

[24] Schaffner, M., Bader, H. P., Scheidegger, R. (2010): Modeling the contribution of pig farming to pollution of the Thachin River. – Clean Technologies and Environmental Policy 12: 407-425.

[25] Schanz, F., Juon, H. (1983): Two different methods of evaluating nutrient limitations of periphyton bioassays, using water from the River Rhine and eight of its tributaries. – Hydrobiologia 102: 187-195.

[26] Schindler, D. W., Hecky, R. E., Findlay, D. L., Stainton, M. P., Parker, B. R., Paterson, M. J., Beaty, K. G., Lyng, M., Kasian, S. E. M. (2008): Eutrophication of lakes cannot be controlled by reducing nitrogen input: results of a 37-year whole-ecosystem experiment. – PNAS 105(32): 11254-11258.

[27] Singh, P., Yadav, B. (2025): Seasonal eutrophication in lentic small waterbodies: understanding nutrients-chlorophyll-a relationships and implications. – Journal of Hazardous Materials Advances 17: 100563. https://doi.org/10.1016/j.hazadv.2024.100563.

[28] Soro, M. P., N'goran, K. M., Ouattara, A. A., Yao, K. M., Kouassi, N. L. B., Diaco, T. (2023): Nitrogen and phosphorus spatio-temporal distribution and fluxes intensifying eutrophication in three tropical rivers of Côte d'Ivoire (West Africa). – Marine Pollution Bulletin 186: 114391. https://doi.org/10.1016/j.marpolbul.2022.114391.

[29] Tian, S., Yang, Y., Qiao, Y., He, W., Lin, J., Wang, D. (2015): Temporal and spatial distribution of phytoplankton chlorophyll-A and its relationship with environmental

factors in Dongjiang River Pearl River basin. – Journal of Lake Sciences 27(1): 31-37. DOI: 10.18307/2015.0104.

[30] Tong, Y., Qiao, Z., Wang, X., Liu, X., Chen. G., Zhang, W., Dong, X., Yan, Z., Han, W., Wang, R., Wang. M., Lin, Y. (2018): Human activities altered water N:P ratios in the populated regions of China. – Chemosphere 210: 1070-1081.

[31] Waajen, G., Lürling, M., van de Sande, R. (2019): The unfulfilled promise of urban Lake Kleine Melanen (The Netherlands): Diagnostics, experiment on reduction of sediment P-release and in-lake restoration. – Lake and Reservoir Management 35(1): 8-24.

[32] Wan, W., Zhang, Y., Cheng, G., Li, X., Qin, Y., He, D. (2020): Dredging mitigates cyanobacterial bloom in eutrophic Lake Nanhu: shifts in associations between the bacterioplankton community and sediment biogeochemistry. – Environmental Research 188: 109799. https://doi.org/10.1016/j.envres.2020.109799.

[33] Wang, Z., Zou, H., Yang, G., Zhang, H., Zhuang, Y. (2014): Spatial-temporal characteristics of chlorophyll-a and its relationship with environmental factors in Lake Taihu. – Journal of Lake Sciences 26(4): 567-575. DOI: 10.18307/2014.0411.

[34] Xu, S. Z., Wang, Y. X., Wang, Y. D., Zhao, Y. J., Gao, Y. (2019): Seasonal influence of reed (*Phragmites australis*) and lotus (*Nelumbo nucifera*) on urban wetland of Yi River. – Applied Ecology and Environmental Research 17(4): 7891-7900.

[35] Yang, D. N., Liu, M. H., Xu, L., Ming, X. Y., Liu, J. M. (2025): Relationship between zooplankton community structure and environmental factors in mudflats wetlands in Qingtongxia Reservoir Area Wetland Nature Reserve, China. – Applied Ecology and Environmental Research 23(1): 291-304.

[36] Zhang, H., Huang, G. H. (2011): Assessment of non-point source pollution using a spatial multicriteria analysis approach. – Ecological Modelling 222: 313-321.

[37] Zhang, J. X., Zhang, L. P., Chai, Q., Shen, Y., Ji, L., Zhao, Q., Li, X., Liu, W., Li, C. M. (2021): Insights into spatiotemporal variations of the water quality in Taihu Lake Basin, China. – Environmental Monitoring and Assessment 193: 757. DOI: 10.1007/s10661-021-09554-5.

[38] Zhang, S. Y., Zhou, Q. H., Xu, D., Lin, J. D., Cheng, S. P., Wu, Z. B. (2010): Effects of sediment dredging on water quality and zooplankton community structure in a shallow eutrophic lake. – Journal of Environmental Sciences 22: 218-224.

[39] Zhang, W. H., Gao, Y., Wang, Y., Zhou, J. (2024): Water quality assessment and management strategies for Nishan Reservoir, Sihe River, and Yihe River Based on scientific evaluation. – Water 16: 1958. https://doi.org/10.3390/w16141958.

[40] Zhang, Z. S., Song, X. L., Lu, X. G., Xue, Z. S. (2013): Ecological stoichiometry of carbon, nitrogen, and phosphorus in estuarine wetland soils: influences of vegetation coverage, plant communities, geomorphology, and seawalls. – Journal of Soils and Sediments 13: 1043-1051.

[41] Zhou, T. T., Hu, W. F., Lai, D. Y. F., Yin, G. G., Ren, D., Guo, Z. L., Zheng, Y., Wang, J. J. (2024): Interaction of reed litter and biochar presences on performances of constructed wetlands Author links open overlay panel. – Water Research 254: 121387. https://doi.org/10.1016/j.watres.2024.121387.

[42] Zhu, W., Feng, G., Liu, Y., Jiang, X., Li, Y., Liu, J., Wang, R., Hu, S., Chen, H. (2019): Influence of environmental dredging on the water quality and studies on sensitive parameters of a typical deep reservoir (Tongjiqiao Reservoir). – Journal of Lake Sciences 31(4): 930-940. DOI: 10.18307/2019.0419.