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Evaluation of Winter Water Purification Efficiency in Lakes by Wetland Ecological Restoration Projects

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Abstract: A study was conducted to evaluate the water quality improvement effects of constructed wetlands on natural lakes, selecting the constructed wetland in the Sino-French Peninsula Town of Houguan Lake in Wuhan as the research subject. The purification performance of the constructed wetland and the water quality status of Houguan Lake were monitored and assessed over a five-month period from November 2024 to March 2025. Field sampling was conducted at five monitoring points within the wetland and Houguan Lake, focusing on five water quality parameters: pH, total nitrogen (TN), total phosphorus (TP), ammonia nitrogen (NH_3^+-N), and chemical oxygen demand (COD). The evaluation employed the single-factor index method, the Nemerow index method, and the Water Quality Index (WQI) method for a comprehensive assessment.

The results demonstrated that the effluent quality of the constructed wetland consistently met Class II standards, significantly outperforming the Class III water quality of Houguan Lake. Average removal rates for total nitrogen (TN), total phosphorus (TP), and ammoniacal nitrogen (NH_3^+-N) were 30%, 60%, and 32% respectively, whilst chemical oxygen demand (COD) removal efficiency remained relatively low at 20%. Seasonal analysis revealed that low winter temperatures reduced the removal rates of TN and TP. In February, phosphorus release from decomposing plant residues led to a peak TP concentration in Houguan Lake (0.117 mg/L, exceeding Class III standards). By March, purification efficiency recovered as temperatures rose. Water Quality Index (WQI) assessment indicated that Chemical Oxygen Demand (COD) was the primary influencing factor in Houguan Lake, whereas Total Nitrogen (TN) dominated in the constructed wetland, with Total Phosphorus (TP) having a minor impact in both. The Nemerow index method confirmed that the constructed wetland's water quality was superior to that of Houguan Lake, though the results were susceptible to outlier interference.

To enhance performance, it is recommended to optimise hydraulic loading to improve COD removal efficiency and strengthen operational management during winter. This research provides a scientific basis for optimising constructed wetland operation under low-temperature conditions and supporting lake ecological restoration.

1. Introduction

1.1 Research Background

Wetlands serve as vital natural purification systems, playing a crucial role in improving lake water quality[1]. However, low winter temperatures significantly suppress microbial activity and plant physiological functions within wetlands, posing substantial challenges to their purification efficiency and creating a seasonal bottleneck in lake pollution control. In recent years, wetland ecological restoration projects have been widely implemented for lake management, yet systematic evaluation of their operational performance during winter remains insufficient[2]. Therefore, scientifically assessing the water purification effectiveness of wetland restoration projects under winter-specific conditions, clarifying their limiting factors and enhancement potential, holds significant importance for optimizing engineering design and achieving year-round water quality assurance. This also provides key references for the ecological management of lakes in similar climatic zones.

1.2 Experimental study area

The constructed wetland in this study area is in the southeast of the Sino - French Wuhan Eco - Demonstration City. Outlined by Houguan Lake's shoreline, it forms a 2.2 - square - kilometer, arc - shaped, three - sided water - surrounded peninsula. There's a 50 - hectare "U" - shaped ecological conservation zone at the lakeside edge, 60% of which is water. The Wuhan Urban Development Group Ecological Design Institute built a three - tiered drainage and purification network of "source sponge - midstream corridor - end - of - pipe wetland" with

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*Corresponding author E-mail address: shiyuan@whc.edu.cn two pathways. Through ecological engineering[3], non - point source pollution was reduced by 70%, reaching Class III water quality and achieving "zero increase" and "zero discharge" of pollution. Dredged silt was used to build ecological islands for various purposes. The water area was divided into an inner lake and an outer lake by hydrodynamic differentiation. This study used systematic sampling to set up five water quality monitoring sections in the core area of the conservation zone to cover key ecological interfaces and sensitive areas. (As shown in Figure 1, the sampling point layout for Houguan Lake and its constructed wetland)

Figure 1 Map of sampling points for Houguan Lake and artificial wetlands

2. Data and Methods

2.1 Empirical Method

Constructed wetlands, an innovative wastewater treatment process, utilize the synergistic effects of physical, chemical, and biological interactions in a substrate - microorganism - plant composite ecosystem. They purify wastewater efficiently via filtration, adsorption, sedimentation, ion exchange, plant uptake, and microbial decomposition[4]. Moreover, they are increasingly recognized because of their stable effluent quality, high shock - load tolerance, low infrastructure and operational costs, easy maintenance, aesthetic value, and good pollutant removal capabilities, such as nitrogen and phosphorus removal.

2.2 Data Sources

In accordance with sampling requirements, systematic sampling and testing of water quality parameters—including total nitrogen, total phosphorus, pH, chemical oxygen demand, and ammonia nitrogen—were conducted at five pre-designated monitoring points (designated S1-S5) within the region from November 2024 to March 2025.

2.3 Water Quality Assessment Methods

The most common evaluation methods are the single - factor pollution index method and the Nemero index method. The latter is chosen by most scholars due to its simple formula for determining main pollutants and pollution degree. Also known as the comprehensive index method, it upgrades and improves based on the single - factor index method, considering both the average and highest values of the pollution index to highlight heavier pollutants and select special pollution indicators. Besides these two methods, water quality evaluation also includes innovative intelligent methods like using machine learning models and GIS software[5].All the following analytical methods are based on the "Surface Water Quality Standard" (GB 3838 - 2002) for evaluation and analysis.

2.3.1 Pollutant Removal Rate

Water quality comparison uses the removal rate of pollutants in water as the analytical indicator

Removal rate = (Concentration of pollutants in the outer lake - Concentration of pollutants in the inner lake) / Concentration of pollutants in the outer lake × 100%

2.3.2 Single Factor Index Method

The single - factor index evaluation method is commonly used by our country's ecological environment department for water environment evaluation[6]. It compares the measured concentration of a single pollutant (e.g., COD, ammonia nitrogen, heavy metals) with the standard limit. The results are clear, easy to understand and apply. The following formula is as follows:

$$\mathrm{p_i} = \frac{C_\mathrm{i}}{S_\mathrm{i}} \tag{1}$$

In the formula, Pi is the single-factor index of the i-th pollutant;

Ci is the measured concentration of the i-th pollutant;

Si is the standard concentration for evaluating the i-th pollutant.

2.3.3 Nemerow Index Method

The Nemerow index method, commonly used by ecological and environmental departments for water quality assessment, is based on the single - factor index method and reflects the overall water pollution level. The calculation formula is:

$$\mathrm{p_i} = \frac{C_\mathrm{i}}{S_\mathrm{i}} \tag{2}$$

$$P = \sqrt{\frac{(\overline{P_\mathrm{i}})^2 + P_{\mathrm{i}\,\mathrm{max}}^2}{2}} \tag{3}$$

Where, Ci is the measured concentration of the i-th pollutant;

S_i is the standard concentration for evaluating the i-th pollutant;

P_{imax} is the maximum value of Pi;

P_i is the average value of Pi.

P is the Nemerow index.

2.3.4 WQI Water Quality Comprehensive Index Analysis Method

The water quality index model integrates multiple water quality parameters into a single value via a mathematical model to intuitively evaluate water body comprehensive quality. The weight Wj formula is:

$$W_j = \frac{1 - E_j}{\sum_{k=1}^{n}(1 - E_k)} \tag{4}$$

$$0 \le W_j \le 1, \quad \sum_{i=1}^{m} W_i = 1$$

The WQI index formula is:

$$WQI_i = \sum_{j=1}^{n} W_j \bullet r_{ij} * 100 \tag{5}$$

3. Results Analysis

3.1 Visualisation and Analysis of Ammonia Nitrogen Removal Efficiency

The ammonia nitrogen removal rate was calculated from Hou Guan Lake and constructed wetland data. Origin software generated a bar chart (Figure 2). Monitoring data shows the constructed wetland effectively removes ammonia nitrogen from Hou Guan Lake water. Initially, the removal rate was consistently high (average 32%), indicating purification capacity. As operation time increased, the overall removal rate slightly declined, which is normal. The highest removal rate (average 64%) was in November, and the lowest (average 8%) was in March. Negative or zero removal rates in the figure need to be analyzed with total nitrogen data. For example, in December S3, despite a negative removal rate, both Hougan Lake and the constructed wetland ammonia nitrogen indices met Class I water quality standards and were within the same - period data waveband. The limited purification space led to the negative removal rate.

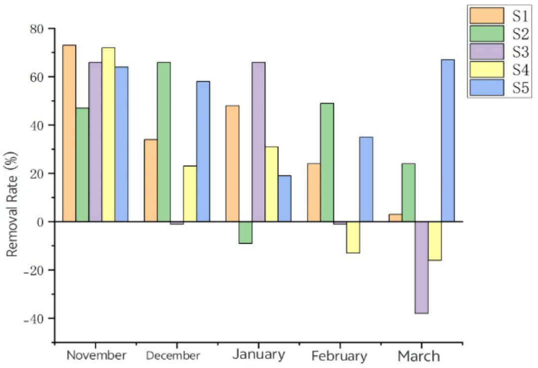

Figure 2 Ammonia Nitrogen Removal Rate Bar Chart

3.2 Visualisation and Analysis of Total Nitrogen Removal Rate

Total nitrogen removal rates were calculated from Hougan Lake and constructed wetland data, and a column chart was generated by Origin software (Figure 3). Monitoring data shows the constructed wetland effectively removes total nitrogen from Hougan Lake water, with an average removal rate of 30%. The optimal removal rate (72% on average) was in November, and the poorest (-3%) was in March. However, the ammonia nitrogen removal rate declined over time, possibly due to seasonal variations. From November to February, Hougan Lake's total nitrogen levels fluctuated little, maintaining Class II water quality. The constructed wetland's total nitrogen increased from December to February, transitioning from Class I to Class II water quality but still achieving a satisfactory removal rate, possibly due to reduced microbial activity and withered vegetation in winter. By March, with rising temperatures and sprouting vegetation, both systems had negative removal rates, but their water quality recovered to Class I. Taking S1 as an example, both Hougan Lake's and the constructed wetland's total nitrogen concentrations met Class I water standards.

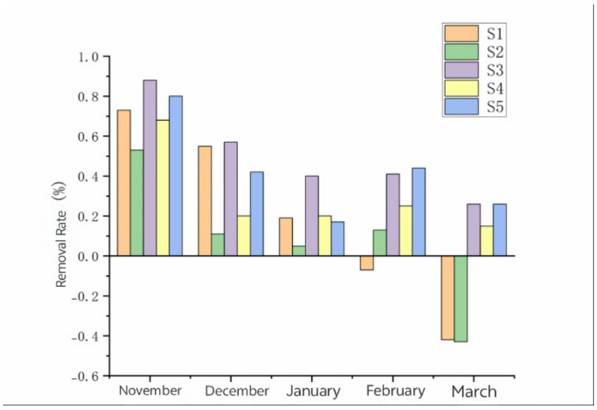

Figure 3 Column Chart of Total Nitrogen Removal Efficiency

3.3 Visualisation and Analysis of Total Phosphorus Removal Efficiency

Total phosphorus removal rates were calculated from Hougan Lake and constructed wetland data, and a bar - chart (Figure 4) was generated by Origin software. Monitoring data shows Hougan Lake's total phosphorus levels mostly met Class III standards with significant fluctuations, while the constructed wetland's levels largely complied with Class II standards and sometimes reached Class I. The graph indicates the constructed wetland had significant total phosphorus removal efficacy, with an average removal rate of 60% (highest 70% in February, lowest 38% in November). In November, for point S3, both Hougan Lake (0.0333 mg/L) and the constructed wetland (0.0352 mg/L) met Class II standards. For the constructed wetland in November, S1 was 0.0161 mg/L, S2 0.0371 mg/L, S4 0.021 mg/L, and S5 0.006 mg/L. Although S3's value was close to S2's, S2 still had a good removal rate. Seasonal factors like plant decomposition and low temperatures can cause negative removal rates in constructed wetlands during total phosphorus removal, usually in February and March, not November. Since there was no prolonged rainfall in November, external phosphorus sources can be excluded. In conclusion, the negative removal rate might be due to improper experimental procedure.

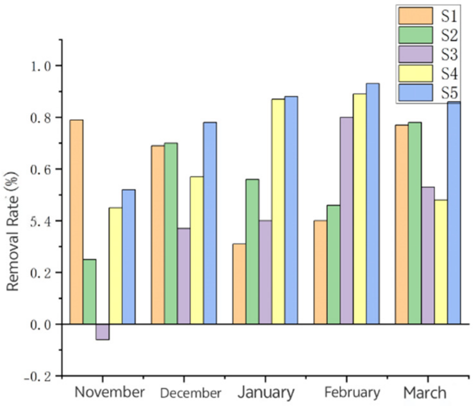

Figure 4 Bar chart of total phosphorus removal rates

3.4 Visualisation and Analysis of COD Removal Rates

COD removal rates were derived from Houguan Lake and constructed wetland COD data, and the trend is shown in Figure 5. Anomalous points occurred in November (S1), December (S2), January (S5), and February (S2), with removal rates in November and February close to zero. In November, COD values at S1 Houguan Lake and artificial wetland were 14.3 mg/L and 14.8 mg/L respectively; in February, those at S2 Houguan Lake and artificial wetland were 14.2 mg/L and 14.4 mg/L respectively. Both showed minimal variation, met Class II water quality standards, and were normal phenomena. After S2 in December, Houguan Lake's COD was 12.3 mg/L, while S2 constructed wetland's was 16.2 mg/L. After S5 in January, Houguan Lake's COD was 9.9 mg/L, a normal value, and S5 constructed wetland's was 14 mg/L. December and January are the low - temperature period, when the constructed wetland's COD trend should decrease. It's possible that the winter water level decline in the constructed wetland led to insufficient hydraulic retention time, causing abnormal COD readings at specific points.

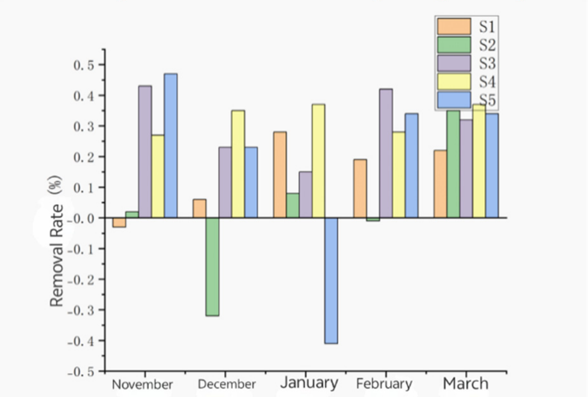

Figure 5 COD Removal Rate Bar Chart

3.5 Nemero Index Method

Integrating single - factor indicators, the Nemero Index was calculated using Grade III standards from the Surface Water Quality Standards (GB 3838 - 2002). Trend charts are available at Figure 6. The Nemero Index of Hougan Lake mostly stayed within Grade III, first declining and then rising. Since it depends on maximum values, it may conceal good conditions of other indicators. In February, monitoring point S5 had peak Nemero Index values because of total nitrogen and total phosphorus exceedances. High Neimero Index readings in November and February (1.448 mg/L and 2.443 mg/L respectively) were due to total phosphorus, leading to poor evaluation results. The Neimero Index classification of the constructed wetland was stable, generally between Grade I and Grade II. The wetland had high removal efficiency for pollutants like TN and TP, preventing large pollution index fluctuations and yielding better water quality than Houguan Lake.

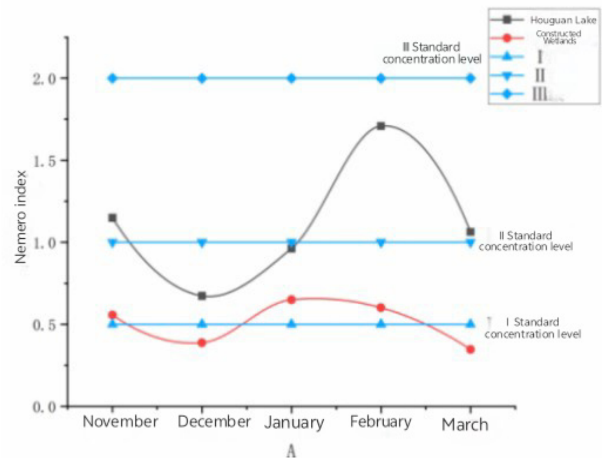

Figure 6: Trend Chart of the Nemero Index Method

3.6 Water Quality Index (WQI) Evaluation for

Based on the data, weights Wj for Houguan Lake and the constructed wetland were calculated and their WQI indices were derived. Origin software was used to generate trend plots (Figure 7). Weighted assessment results indicate that in Houguan Lake, COD is the primary pollutant and total phosphorus (TP) has the least influence, showing organic - pollution - dominant water quality. In the constructed wetland, total nitrogen (TN) is the main pollutant and TP contributes the least, indicating nitrogen pollution. Since both sites have minimal TP impact, it shows effective phosphorus control. Recommendations are to intensify COD reduction in Houguan Lake and optimize denitrification in the constructed wetland.

Trend analysis reveals that the WQI index of the constructed wetland decreased from November to February, hitting the lowest in February (possibly due to less management during the Spring Festival and water - quality deterioration), and then increased in March as management resumed. The constructed wetland has an average WQI of 63.26, with moderate (Class III) water quality. Houguan Lake's WQI showed an upward trend during monitoring, with an average of 57.25. The artificial wetland can improve water quality under normal management but needs continuous maintenance for stability. Houguan Lake is gradually improving, yet more pollution - control measures are needed.

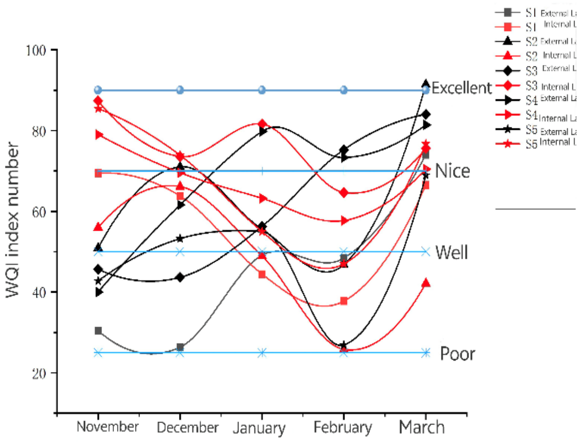

Figure 7 WQI Trend Chart

4. Conclusion

Overall, both Houguan Lake and the constructed wetland have favourable water quality. The constructed wetland mostly maintains Class II standards, while Houguan Lake maintains Class III standards. The constructed wetland has significant purification effects on Houguan Lake's water quality, with average removal rates of 32% for ammonia nitrogen, 30% for total nitrogen, 60% for total phosphorus, and 20% for COD. The artificial wetland shows pronounced purification efficacy, with better total phosphorus removal in the inner lake than the outer lake. Both ammonia nitrogen and total nitrogen have high removal rates in both lakes, indicating strong biochemical degradation capacity.

Among pollutants, total phosphorus has the highest removal rate (60%), and COD has the lowest (20%). Evaluated by the Nemero Index, Houguan Lake is Grade III (slightly polluted), and the constructed wetland is Grade II (virtually unpolluted). By the Water Quality Index (WQI) assessment, COD is the key factor affecting Hougan Lake's water - quality grade, while total phosphorus contributes less to pollution. For the constructed wetland, total nitrogen (TN) is the primary pollutant, and total phosphorus has the lowest weighting due to efficient removal. The average WQI of the constructed wetland is better than that of Hougan Lake, showing its good purification efficiency for Hougan Lake's water quality.

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References

1. Research Progress on Microbial Enhanced Pollutant Removal in Constructed Wetlands by Zhang Juan, Wang Chenchen et al. Environmental Science and Resource Utilization X703;X172
2. Zhong Qijun, Zhou Zeyou et al. Application of constructed wetlands in the treatment of organic matter polluted water bodies in river basins. Environmental Science and Resource Utilization, X52;X824
3. Wen Shanshan, Wang Youchun et al. Development and Application of Key Technologies for Ecological Engineering Governance of Rivers and Lakes in the New Era. Environmental Science and Resource Utilization; Water Resources and Hydropower Engineering TV85; X171.4; X832
4. Li Junhua. Analysis and Evaluation of the Water Quality Improvement Effect of Constructed Wetlands on Xiao River [D]. Hebei University of Science and Technology, 2016.
5. Entropy method for determination of weight of evaluating indicators in fuzzy synthetic evaluation for water quality assessment[J].Journal of Environmental Sciences,2006,(05):1020-1023.
6. Xu Zuxin Research on the Evaluation Method of Single-Factor Water Quality Indicator Index for Rivers in China Environmental Science and Resource Utilization X824