Efficacy Analysis of Ancient Town River Treatment Using Microbial Technology—A Case Study of Luzhi Ancient Town River Treatment in China

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Abstract. The river water environment treatment in historical and cultural ancient towns generally faces multiple challenges, such as complex pollution sources, poor water flow, limited ecological space, and the need for cultural heritage and landscape protection. Traditional large-scale hydraulic or biochemical engineering is difficult to apply. This study selected a 1000-meter typical river section (initial water quality: worse than Grade V) in Luzhi Ancient Town, Suzhou City, Jiangsu Province, deployed a distributed microbial integrated treatment device, and conducted an in-situ remediation pilot study for about 1.5 months (from August 1 to September 12, 2025). The results show that the system exhibited good pollutant removal effects without significantly impacting the ancient town's landscape or navigation. After 45 days of operation, the concentrations of ammonia nitrogen (NH3-N), total nitrogen (TN), and total phosphorus (TP) at each monitoring point decreased significantly, with TN removal rates reaching 77.8%-82.3% and TP removal rates reaching 82.5%-85.0%. Water quality indicators improved from worse than Grade V to Grade III~V surface water standards, and water body turbidity was visibly reduced with significant sensory improvement. The study confirms that distributed microbial in-situ remediation technology is a low-impact, high-efficiency, and environment-friendly viable solution for solving such water environment problems in spatially sensitive areas.

Keywords: Ancient Town River, In-situ Remediation, Distributed Equipment, Microbial Augmentation, Eutrophication, Efficacy Analysis.

1. Introduction

With the process of urbanization, the rapid development of tourism in ancient towns has brought enormous pressure on the water environment. Unlike general urban rivers, the rivers in historical and cultural ancient towns (such as the Jiangnan water towns) usually have characteristics like poor hydrodynamic conditions (slow flow or even stagnant), weak water self-purification capacity, direct discharge of domestic sewage and tourism point source pollution, and a lack of ecological shorelines [1, 2]. The water bodies are extremely prone to eutrophication, leading to algal blooms and water turbidity, which seriously affects the landscape value and living environment of the ancient towns.

However, the treatment of rivers in ancient towns is greatly restricted. First, the protection requirements for cultural relics and historical buildings are high, making large-scale excavation or civil engineering impossible. Second, the rivers are narrow and serve navigation functions, making it difficult for large-scale equipment to enter. Traditional river treatment technologies thus face a dilemma of "unsuitability." For example, although physical dredging can quickly remove sediment, it causes significant engineering disturbance, is costly, and only treats the symptoms, not the root cause, failing to control continuous pollution input into the river [3]. Aeration and oxygenation can only increase the dissolved oxygen in the water, with limited removal effects on key nutrients like total nitrogen (TN) and total phosphorus (TP) [4]. While constructed wetlands or ecological ponds have excellent nitrogen and phosphorus purification capabilities, they require vast land areas [5, 6], which is almost impossible in the extremely space-constrained core areas of ancient towns where land is precious.

Therefore, finding a technology that occupies little space, is simple to construct, does not damage the landscape, does not affect navigation, and can efficiently remove nitrogen and phosphorus pollution in-situ is an urgent need in the current field of ancient town river remediation [7].

The concept of "distributed in-situ remediation" has emerged as a result. This technology purifies the water body on-site by deploying small-scale, high-efficiency treatment units within the polluted river section. Among these, biofilm technologies based on immobilized microorganisms (such as Moving Bed Biofilm Reactor, MBBR) have received much attention due to their high microbial biomass, strong resistance to shock loads, and no need for sludge return. The microbial integrated equipment used in this study is based on this principle. It constructs a high-density biofilm system by immobilizing a composite microbial community, cored on species like Nitrosomonas europaea (a key ammonia-oxidizing bacterium, AOB [8]) and Pseudomonas stutzeri (with efficient denitrification and phosphorus accumulation capabilities [9]), onto high-efficiency carriers, thereby achieving efficient removal of nitrogen and phosphorus.

This study takes the worse-than-Grade-V river in Luzhi Ancient Town, Suzhou, as the experimental subject. Its core objective is to, through an in-situ pilot-scale experiment, not only verify the pollutant removal efficacy of this distributed microbial equipment in a real ancient town river environment but also to analyze its operational start-up characteristics and stability, and ultimately to explore its applicability and limitations in such specific scenarios.

2. Materials and Methods

2.1. Study Area Overview

The study site is located in the core area of Luzhi Ancient Town (Figure 1), Wuzhong District, Suzhou City, Jiangsu Province. The area has a subtropical monsoon climate with distinct four seasons and abundant rainfall. The experimental river section has a total length of about 1000 meters, composed of 3 connected segments, with a river width of 3-8 meters, water depth of 1.5-2.0 meters, and slow flow velocity (about 2-3 m/min). The river banks are mostly stone-built, lacking aquatic vegetation, and water exchange is poor.

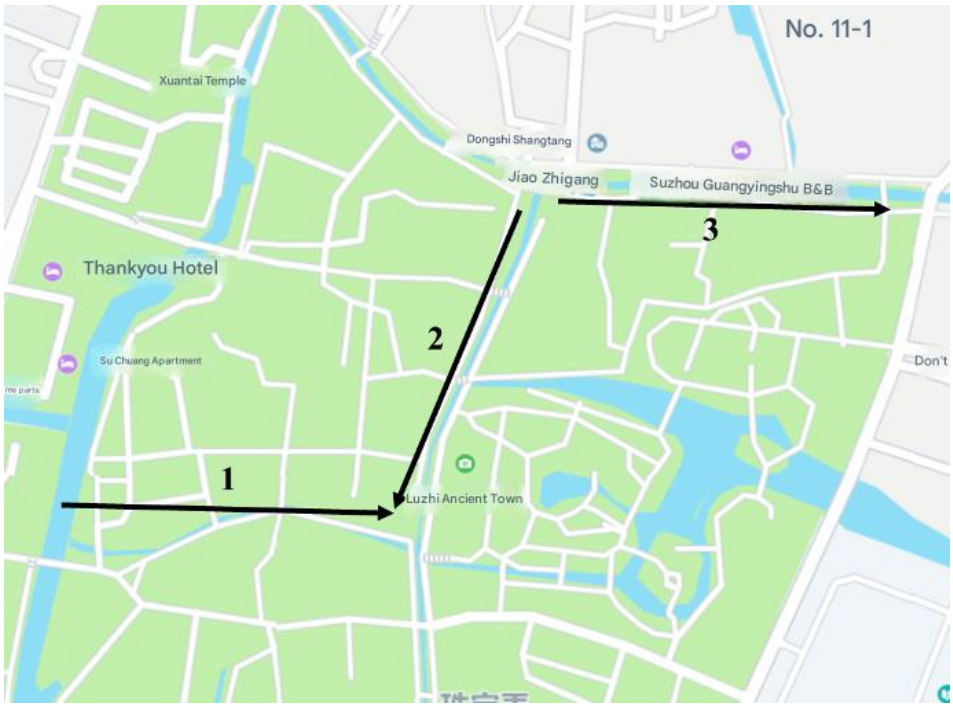


Figure 1. Map of the river proposed for treatment in Luzhi Ancient Town.

2.2. Initial Water Quality Status and Pollution Source Analysis

According to the on-site investigation, domestic sewage (from washing, kitchen waste, etc.) from residents along the river is mostly discharged directly into the river without treatment, and tourist boats navigating the river cause water disturbance. To assess the background water quality, water samples were collected on June 9, 2025 (before treatment) from the upstream (River Section 1) and the mid-downstream (junction of River Sections 2 and 3) of the experimental river section. The test results are shown in Table 1.

Table 1. Initial River Water Quality Before Treatment (June 9, 2025).

Sampling Point	COD (mg/L)	NH3-N (mg/L)	NO3-N (mg/L)	TN (mg/L)	TP (mg/L)
River Section 1	26.1	3.16	4.57	7.92	1.21
Junction	24.3	3.48	4.91	8.60	1.13

According to the "Environmental Quality Standards for Surface Water" (GB 3838-2002) [10], the overall water quality of this river section is worse than Grade V. The main pollution factors are ammonia nitrogen, total nitrogen, and total phosphorus, showing obvious eutrophication.

2.3. Experimental Equipment and Microbial Agents

The core treatment unit in this study is the "distributed microbial integrated equipment." This device is an in-situ purification unit based on the biofilm principle. Its interior is filled with high-specific-surface-area biological carriers used to immobilize and cultivate a high-density composite microbial community. The core microbial community (including but not limited to N. europaea [8] and P. stutzeri [9]) forms a biofilm on the carrier surface. Through the device's internal water flow organization, the river water is brought into full contact with the biofilm.

The core of pollutant removal in this system lies in the synergistic effect of the biofilm. Specifically, nitrification (by AOBs, etc.) in the aerobic zone converts ammonia nitrogen (NH3-N) to nitrate nitrogen (NO3-N); meanwhile, denitrification (by P. stutzeri, etc.) in the anoxic zone uses organic matter (COD) in the water as a carbon source to reduce nitrate nitrogen to nitrogen gas (N2), which escapes; finally, phosphorus-accumulating organisms (PAOs, such as some Pseudomonas species) transfer phosphorus from the water body into the microbial cells through anaerobic phosphorus release and aerobic phosphorus uptake processes, achieving phosphorus removal [11].

2.4. Experimental Design and Monitoring

A total of 3 sets of microbial integrated equipment were installed and fixed in the upstream, midstream, and downstream of the experimental river section. The equipment occupied minimal river space and did not affect tourist boat navigation. The equipment was commissioned on July 24, 2025, and officially started operation on August 1, 2025.

Water quality monitoring points (Point 1, Point 2, Point 3) were established near the 3 equipment deployment sites. From the equipment start-up (July 28, 2025) to September 12, 2025, water samples were collected regularly. Analyzed indicators included COD, ammonia nitrogen, nitrate nitrogen, total nitrogen, and total phosphorus. All water sample collection, preservation, and analysis were performed in accordance with the standard methods in the "Environmental Quality Standards for Surface Water" (GB 3838-2002) [10].

3. Results and Discussion

3.1. System Efficacy on Main Pollutant Removal

The water quality change data at each monitoring point during the experimental period are shown in Table 2. Figure 2 visually displays the change trend of main pollutant concentrations.

Table 2. Water Quality Data Record at Each Monitoring Point During Treatment.

Date	Location	COD (mg/L)	NH3-N (mg/L)	NO3-N (mg/L)	TN (mg/L)	TP (mg/L)
2025/7/28	1	6.12	3.12	4.55	7.88	1.23
2025/7/28	2	6.25	3.24	4.94	8.54	1.06
2025/7/28	3	6.14	3.08	4.23	8.12	1.04
2025/8/15	1	16.8	3.63	4.32	8.04	0.256
2025/8/15	2	14.2	3.82	4.88	8.82	0.308
2025/8/15	3	13.5	3.21	4.64	8.08	0.312
2025/9/12	1	8.12	1.13	0.22	1.43	0.185
2025/9/12	2	9.23	1.25	0.26	1.51	0.186
2025/9/12	3	8.64	1.34	0.43	1.80	0.177

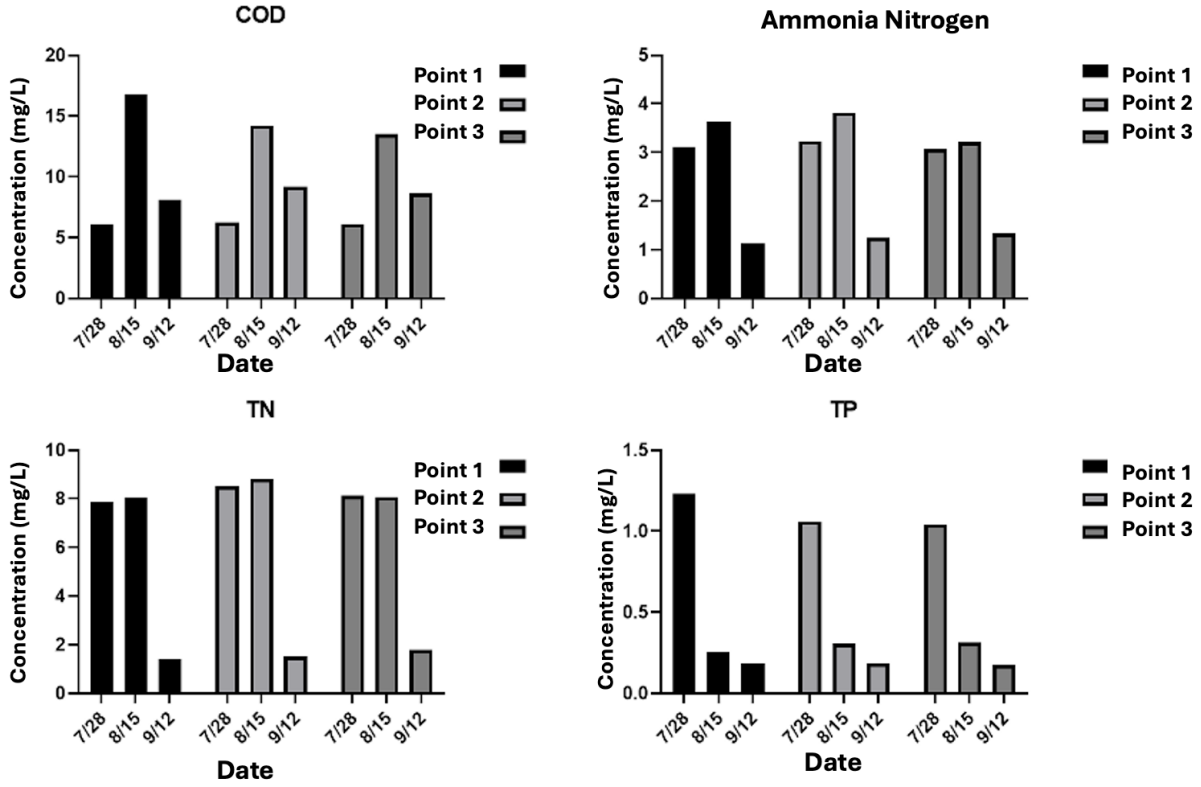


Figure 2. Trend of pollutant concentration changes at each monitoring point.

3.1.1. Phosphorus Removal (TP) Efficacy

As shown in Figure 2, the start-up of TP removal was very rapid. After only about 15 days of operation (August 15, 2025), the TP concentration at all 3 monitoring points dropped sharply from an initial >1.0 mg/L to around 0.3 mg/L, with an average removal rate exceeding 70%. By September 12, 2025, the TP concentration further decreased to an average of 0.183 mg/L (Grade III water

standard), with a total removal rate as high as 82.5%-85.0%. This indicates that the phosphorus-accumulating organisms (PAOs) in the system could quickly colonize and exert efficient biological phosphorus uptake [11].

3.1.2. Nitrogen Removal (NH3-N, TN) Efficacy

Unlike TP, nitrogen removal exhibited a significant "lag." On August 15, 2025, the concentrations of NH3-N and TN showed no decrease compared to the initial values (July 28, 2025), and even slightly increased. However, by September 12, 2025, both NH3-N and TN concentrations showed a "cliff-like" drop, with NH3-N decreasing to an average of 1.24 mg/L (Grade IV water standard) and TN decreasing to an average of 1.58 mg/L (Grade V water standard). The total removal rate for TN reached 77.8%-82.3%.

This "P-first, then-N" phenomenon is not surprising; it is a typical characteristic of biofilm system start-up, especially for nitrification systems [12]. It is well-known that nitrifying bacteria (like N. europaea) are autotrophs with long generation cycles and slow growth [13]. The complete attachment and maturation of their biofilm usually require 30-45 days. Therefore, the data from August 15, 2025, precisely indicate that the system was still in the start-up phase, while the data from September 12, 2025, signify that the nitrification-denitrification microbial community had successfully enriched and was operating efficiently.

3.2. Operational Fluctuations and Environmental Disturbance Analysis

This study was conducted in a real, open ancient town river, where water quality is inevitably subject to external disturbances. The data from August 15, 2025 (Table II) show that while TP dropped significantly, the concentrations of COD, NH3-N, and TN all rebounded slightly.

It should not be seen as an equipment failure, but rather attribute it to a response to an "external shock load." The water quality of ancient town rivers is extremely susceptible to influences from upstream inflow, instantaneous discharge of domestic sewage from both banks, tourism peaks, or strong rainfall-runoff [14]. This fluctuation was most likely caused by the aforementioned factors.

What is noteworthy, however, is that even under the shock load of COD and N, the system's phosphorus removal function (TP) remained stable and efficient (continuously decreasing). This indicates that the activity of PAOs in the system was relatively robust. In a sense, this process instead proves that the microbial system possesses good resilience and recovery capabilities in a real, fluctuating river environment, i.e., the system could quickly recover after the shock and (by September 12, 2025) demonstrate strong nitrogen removal capabilities.

3.3. Water Body Sensory Improvement and Ecological Effects

Besides the quantitative water quality data, the treatment effect was most directly reflected in the water body's sensory perception. The river water before treatment was turbid, yellowish-green, and showed clear signs of eutrophication.

After about 1.5 months of treatment, the water transparency significantly improved, the color (chroma) markedly improved, surface garbage decreased, and the sensory perception was greatly enhanced. The mechanism behind this is clear: after key nutrients like N and P were largely removed, algae (phytoplankton) in the water lost their growth advantage, their biomass decreased [15], and thus water transparency increased, the water color improved, achieving a transformation from "turbid" to "clear."

3.4. Overall Technology Evaluation and Limitations

Compared to the traditional technologies mentioned in the introduction, the distributed microbial equipment used in this study demonstrates unique applicability in the treatment of ancient town rivers. First, it is spatially friendly; the equipment is directly installed in the river, occupying no extra land or water surface, making it an ideal choice for extremely space-constrained ancient towns. Second, it achieves low environmental impact, avoiding the excavation and landscape damage caused by large-

scale dredging [3] or wetland construction [5, 6], thereby protecting the historical landscape of the ancient town. Furthermore, the equipment does not affect the river's navigation function, achieving functional compatibility. Most importantly, compared to aeration technology which only increases oxygen [4], this technology can efficiently remove N and P nutrients, controlling eutrophication and algal blooms from the source, thus achieving an efficient root-cause treatment.

Despite the good results achieved, this study itself has some obvious limitations. The most significant is the limitation of the monitoring period; the experiment was mainly concentrated in the summer-autumn season (August-September 2025), a temperature suitable for microbial growth. The system's operational efficacy under low-temperature conditions (e.g., winter) requires further study [16]. Second, the monitoring indicators were not comprehensive enough. For example, there was a lack of quantitative monitoring of process indicators such as dissolved oxygen (DO), suspended solids (SS), or turbidity (NTU), nor was a detailed analysis of the microbial community structure conducted. Finally, in terms of cost-effectiveness, the long-term operating energy consumption, maintenance costs, and carrier lifespan of the equipment were not accounted for.

4. Conclusions

Through the in-situ remediation experiment using distributed microbial integrated equipment conducted in the worse-than-Grade-V river of Luzhi Ancient Town, Suzhou, the following conclusions can be drawn. First, this technology has good feasibility and applicability in space-constrained ancient town rivers with high landscape protection requirements, achieving low-impact construction and efficient in-situ purification. Second, after about 45 days of operation, the system showed excellent removal effects on nitrogen and phosphorus nutrients. The average removal rates for TN and TP reached approximately 81% and 84%, respectively, and the water quality significantly improved from worse than Grade V to Grade III~V surface water standards. Concurrently, this study also observed that the system start-up exhibited a "fast-first, then-slow" (fast P removal, slow N removal) typical biofilm attachment characteristic, and showed good operational resilience to pollution shock loads in the real river. Finally, by effectively removing N and P, the system suppressed algal growth from the source, significantly improving water transparency and greatly enhancing sensory perception.

In summary, distributed microbial in-situ remediation technology is a low-impact solution with great potential for treating eutrophication in environmentally sensitive areas such as ancient town rivers.

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