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Assessment and Comprehensive Evaluation of Large-Scale Reclaimed Water Reuse for Urban River Restoration and Water Resource Management: A Case Study in China

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Abstract: Replenishing reclaimed water into urban rivers, which suffer from reduced flow and deteriorating water quality due to anthropogenic activities, presents an opportunity for water resource management and ecological restoration, while the effect and evaluation need to be considered. This study investigated the feasibility of large-scale reclaimed water reuse in urban rivers, focusing on water quality improvements and reuse scheme evaluation, utilizing modeling software to simulate the water quality after implementing the reclaimed water replenishment scheme. After seven days of reclaimed water replenishment simulated, the water quality in the receiving urban rivers exhibited substantial improvements to different extents, with some rivers showing a decrease of over 90% in chemical oxygen demand (COD_{Mn}), ammonia nitrogen (NH_3-N), and total phosphorus (TP) concentrations. A comprehensive evaluation method using the physical element extension–analytic hierarchy process (AHP) evaluation model was developed to evaluate the feasibility and efficiency of the large-scale project of reclaimed water reuse in urban rivers. The overall score of the large-scale reclaimed water reuse scenario reaches 89, approaching Level I and indicating a highly scientific and reasonable plan. This study contributes to the field of urban river restoration and water resource management by demonstrating the potential for improving water quality in urban rivers through large-scale reclaimed water reuse. The innovative comprehensive evaluation method offers valuable insights for guiding the implementation of similar projects in other urban river systems, addressing water resource challenges, and promoting ecological restoration in urban areas.

Keywords: reclaimed water; water reuse; urban rivers; scheme evaluation; wastewater reclamation

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Citation: Lin, X.; Li, S.; Sun, D.; Zhou, W.; Wei, J.; Fang, H.; Zhu, L.; Lu, Z.; Xu, J. Assessment and Comprehensive Evaluation of Large-Scale Reclaimed Water Reuse for Urban River Restoration and Water Resource Management: A Case Study in China. *Water* **2023**, *15*, 3909. https://doi.org/10.3390/w15223909

Academic Editor: Carmen Teodosiu

Received: 8 October 2023
Revised: 4 November 2023
Accepted: 7 November 2023
Published: 9 November 2023

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1. Introduction

The rapid urbanization and population growth in global cities have put immense pressure on conventional water sources, necessitating the exploration of alternative water supply options. Reclaimed water, which is treated wastewater that meets specific quality standards, has emerged as a sustainable solution to mitigate water scarcity and promote environmental sustainability [1,2]. Urban rivers often suffer from reduced flow and deteriorating water quality due to various anthropogenic activities [3–5]. Integrating reclaimed water into urban river systems presents an opportunity to address both water resource challenges and ecological restoration [6–8].

In recent years, there has been a growing interest in the application of reclaimed water reuse for urban river replenishment [9–11]. Studies have explored various aspects of this approach to assess its feasibility and potential benefits, including the technical aspects of water treatment, water quality analysis, hydrological modeling, and ecological assessments [12–15]. One significant area of research is the development of advanced water

treatment technologies for reclaimed water. Studies have investigated innovative treatment processes such as membrane filtration, advanced oxidation, and biological treatment to ensure that reclaimed water meets the required quality standards for safe reuse [16–18]. These advancements have significantly improved the reliability and safety of reclaimed water, making it a viable option for urban river replenishment. Another key aspect of research progress is the assessment of the environmental impacts of reclaimed water reuse in urban rivers [19,20]. Ecological studies have been conducted to understand the potential effects of introducing reclaimed water into river ecosystems. Researchers have examined changes in aquatic habitats, biodiversity, and the overall ecological health of urban rivers after implementing large-scale reclaimed water reuse projects [7,21]. These studies have provided valuable insights into the potential benefits and risks associated with this approach.

Despite the development and progress made, several challenges and limitations have been identified in the research on reclaimed water reuse in urban rivers. Public perception and acceptance remain significant hurdles, as there are concerns about the safety and aesthetic aspects of using reclaimed water for river replenishment [18,22–25]. Water quality variability and uncertainty pose additional challenges. Previous studies on reclaimed water reuse in urban rivers have primarily focused on small-scale water networks, typically involving one or two urban rivers [8,26]. However, when considering large-scale reclaimed water reuse, concerns arise regarding its potential impact on the water quality and hydrodynamics of the entire river network. Furthermore, in large-scale reclaimed water reuse projects, assessing the feasibility of its application and evaluating the science and rationality of replenishment schemes are critical issues for the advancement of reclaimed water reuse in urban rivers. Some studies developed a few methods including life cycle assessment, analytic hierarchy process (AHP), and other comprehensive evaluation methods to evaluate the benefits of projects, technologies, or processes [27,28], while evaluations of water reuse engineering schemes are rarely reported.

Therefore, this study aims to investigate the feasibility of large-scale reclaimed water reuse in urban rivers for water resource management and ecological restoration by highlighting substantial water quality improvements and introducing a novel evaluation approach. Based on a large-scale water reuse project, the water quality of the receiving reivers replenished with a large amount of reclaimed water is simulated by a model and software. And then, an innovative comprehensive evaluation method based on the physical element extension–AHP model is developed and applied to assess the efficiency and feasibility of the large-scale reclaimed water reuse project. This research may provide valuable insights for guiding the implementation of similar reclaimed water reuse projects in other urban river systems, helping to address water resource challenges and promote ecological restoration in urban areas.

2. Materials and Methods

2.1. Project Profile

In recent years, City NB City has been at the forefront of water environmental management and recycled water reuse among numerous cities in China. Over the past decade, a series of water treatment measures, such as the remediation of polluted and foul-smelling water bodies, pilot projects for recycled water reuse, and ecological restoration of river channels, have significantly improved the water environmental quality in the urban area and alleviated the problem of water resource scarcity. Previous studies conducted by our research group in City NB have also demonstrated the feasibility of using recycled water for landscape irrigation and the ecological restoration of river channels [8,23,26]. To further alleviate the current shortage of ecological replenishment water in urban rivers and improve the overall water environmental quality in the region, we propose to promote large-scale reuse of recycled water from wastewater treatment plants for the ecological replenishment of waterways. With the upgraded wastewater treatment plant within the project scope, the total capacity of recycled water can be increased to 100,000 m^3/day. However, the water

network within the project area is dense, and the water quality varies greatly, making the hydraulic situation complex and the need for water quality improvement urgent.

In this study, the geocoordinate range of the location of the case project ranges from approximately 121.56–121.61° E and 29.86–29.90° N. Additionally, 100,000 m^3 of reclaimed water is produced and replenished into 21 urban rivers from two locations, as shown in Figure 1. River 02 will receive a daily replenishment of 87,000 m^3, while River L will receive 13,000 m^3. The joint scheduling will consider the actual opening frequency and the effectiveness of the water diversion on an annual basis.

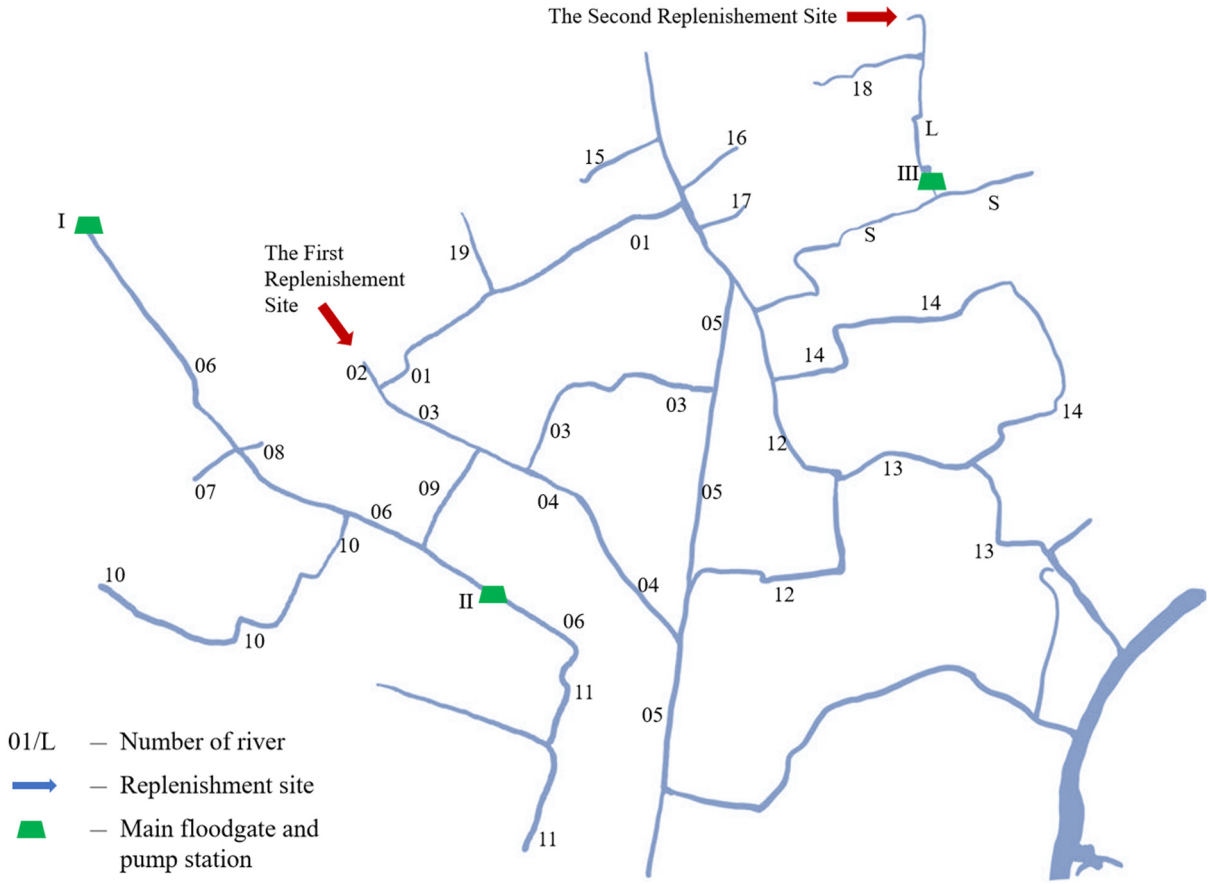


Figure 1. Large-scale reclaimed water reuse in urban rivers.

2.2. Model Establishment and Simulation

Combining the water quality and hydrological survey data of the receiving rivers replenished with reclaimed water, MIKE11 (version of 2016, DHI company, Hørsholm, Denmark) was used to conduct hydraulic and water quality modeling and optimization of the engineering scheme for replenishing the reclaimed water reuse into urban rivers [29]. The main processes of model establishment and simulation are as follows:

(1) Establishment of river network files and cross-sectional shapes

The shape of the City NB river network is determined based on Baidu Maps and the cross-sections of these rivers are measured in the project, with representative results shown in Figure S1. The simulated river network mainly includes 21 urban rivers, as shown in Figure 1. Various hydraulic structures are set up in the model based on the data collected, including 5 water gates, 5 pump stations, and 1 rubber dam. The cross-sectional data of each river section are obtained from actual measurements, and for sections where measurements are unavailable or difficult to measure, data from adjacent river sections are used. The data regarding the distance 'x' from the cruise data and the riverbed elevation 'z' for the simulated river section are edited into a specific format as a text file, which is then

imported into MIKE 11 to generate cross-sectional files. These files accurately depict the riverbed topography. Representative cross-sections of the river are shown in Figure S1.

(2) Establishment of time series files

The time series files include water level and flow data, where different types of data are placed within the same time series file on the same time axis. The fundamental data are obtained from two stations in City NB and are used to establish the tidal time series file for River YJ, accurately reflecting the tidal fluctuations in River YJ, as shown in Figure S2. During July, when the water level of River YJ is lower than that of the urban rivers during daily low tide, the urban river water gates are opened for drainage. Different scenarios are used to establish time series files for the scheduling of various gates leading to River YJ. The pumping station pumping water from the west of River S to the east of River S operates 24 h a day with a flow rate of 0.046 m^3/s, while the pumping station pumping water from River S to River 14 operates for 8 h daily with a flow rate of 0.306 m^3/s.

(3) Establishment of boundary conditions

The wastewater treatment plant will provide 100,000 m^3/d of reclaimed water. The model's boundary conditions are set as follows: The replenishment amount at the first replenishment site for reclaimed water is 87,000 m^3/d, and the amount at the second replenishment site is 13,000 m^3/d. The concentrations of pollutants in the reclaimed water are as follows: ammonia nitrogen (NH_3-N, an inorganic chemical compound of nitrogen and hydrogen with the formula NH_3) concentration is 1.5 mg/L, chemical oxygen demand (COD_{Mn}, a water quality parameter that measures the amount of oxygen required to chemically oxidize the pollutants in water) concentration is 6 mg/L, and total phosphorus (TP, all the forms of phosphorus including orthophosphate, condensed phosphate, and organic phosphate in the sample) concentration is 0.3 mg/L. Since the river channels are connected to River YJ and are affected by tides, a tidal time series file, as shown in Figure S3, is imported and boundary pollutant concentrations are set accordingly. Due to the lack of relevant data, the model currently does not consider the impact of rainfall and external pollution.

(4) Establishment of model parameter files

The model sets the initial water level for urban rivers in City NB at 1.35 m (design normal water level). The initial pollutant concentrations are based on the actual water quality in the urban rivers of City NB. For pollutants with available monitoring data in the river channels, the average values of the measured data are used as the initial values for simulation. The initial concentrations for each river channel are listed in Table S1. The river bed roughness is set to 0.03, considering the riverbed morphology and material characteristics.

2.3. Comprehensive Evaluation of Reclaimed Water Reuse in Urban Rivers

In this study, based on our research group's studies on the synergy of water quality standards for reclaimed water reuse in rivers and algal bloom risks, as well as the research on the monitoring and evaluation of reclaimed water quality and the river, a comprehensive evaluation method for reclaimed water reuse in rivers is developed and applied. This method considers algal bloom risk control and hydraulic improvements, and utilizes the physical element extension–AHP evaluation model. The main steps of this method include calculating indicator weights and indicator correlation.

(1) Calculation of Indicator Weights

When using the AHP method to calculate weights, the weights of primary indicators are determined first, and then the weights of secondary indicators are determined. The procedure involves pairwise comparisons of each indicator using the (0, 1, 2) scale method to establish the relative order of preference. The comparison results form a three-scale comparison matrix C, where c_{ij} = 2, 1, or 0, which represents the importance of indicator i compared to indicator j as more important, equally important, or not important, respectively. The specific steps for calculating weights are described in Text S1.

(2) Indicator Correlation Calculation

① Matter-Element Extension Evaluation Factors

In practical applications, according to the evaluation system, the same-level indicators are selected as evaluation factors. The evaluation objects are classified into five levels from high to low: high, relatively high, moderate, relatively low, and low. Each evaluation level is assigned a corresponding score value: (high, relatively high, moderate, relatively low, low) = (95, 85, 75, 65, 40). The level divisions and numerical values for the evaluation factor indicators are determined, and the levels are represented by intervals: [0.8, 1], [0.6, 0.8), [0.4, 0.6), [0.2, 0.4), and [0, 0.2), respectively.

② Correlation Matrix

Based on the indicator system, the evaluation vectors for the secondary indicators are determined, and an evaluation indicator matrix is established. The evaluation values in the indicator matrix are normalized to fall within the interval [0, 1]. After the normalization process, the correlation matrix K is calculated using the correlation function. The evaluation levels are quantified using a hundred-point score system for the comprehensive evaluation of reclaimed water reuse in river water quality. The comprehensive correlation $K_j(G_i)$ is obtained using the correlation matrix K and the weight vector W by Equation (1).

$$K_j(G_i) = W^T \quad (1)$$

Unlike the Dempster–Shafer theory, where the maximum correlation is used as the evaluation criterion, this evaluation method normalizes the comprehensive correlations for each level and transforms them into indices to avoid limitations in using correlations as evaluation criteria. The corresponding levels for the indices are shown in Table 1.

Table 1. Corresponding grading levels of comprehensive index score.

Score	Grade	Explanation
90~100	I	Excellent
80~90	II	Good
70~80	III	Fair
60~70	IV	Poor
20~60	V	Bad

3. Results and Discussions

3.1. Analysis of Initial Water Quality of Receiving Rivers

Water quality monitoring and data analysis were conducted on the rivers within the research scope, and the concentrations of COD_{Mn}, NH_3-N, and TP are shown in Figure 2 and Table S1. The initial distribution of COD_{Mn} concentrations in the rivers ranges from 2.89 to 8.81 mg/L, all meeting the Class IV surface water requirement (as shown in Table S2) of 10 mg/L, and half of them meeting the Class III surface water requirement of 6 mg/L. To further improve the COD_{Mn} indicator in the river after reuse, the COD_{Mn} concentration in the reclaimed water should ideally be reduced to 6 mg/L. The initial NH_3-N concentrations were all severely exceeding the standards, with only a few sampling points meeting the Class IV surface water requirement of 1.5 mg/L, resulting in a compliance rate of 12.9%. TP concentrations are all above the standards. Therefore, the primary goal of reclaimed water reuse is to achieve compliance with nitrogen and phosphorus concentrations in the river after reuse and reduce the risk of algal blooms.

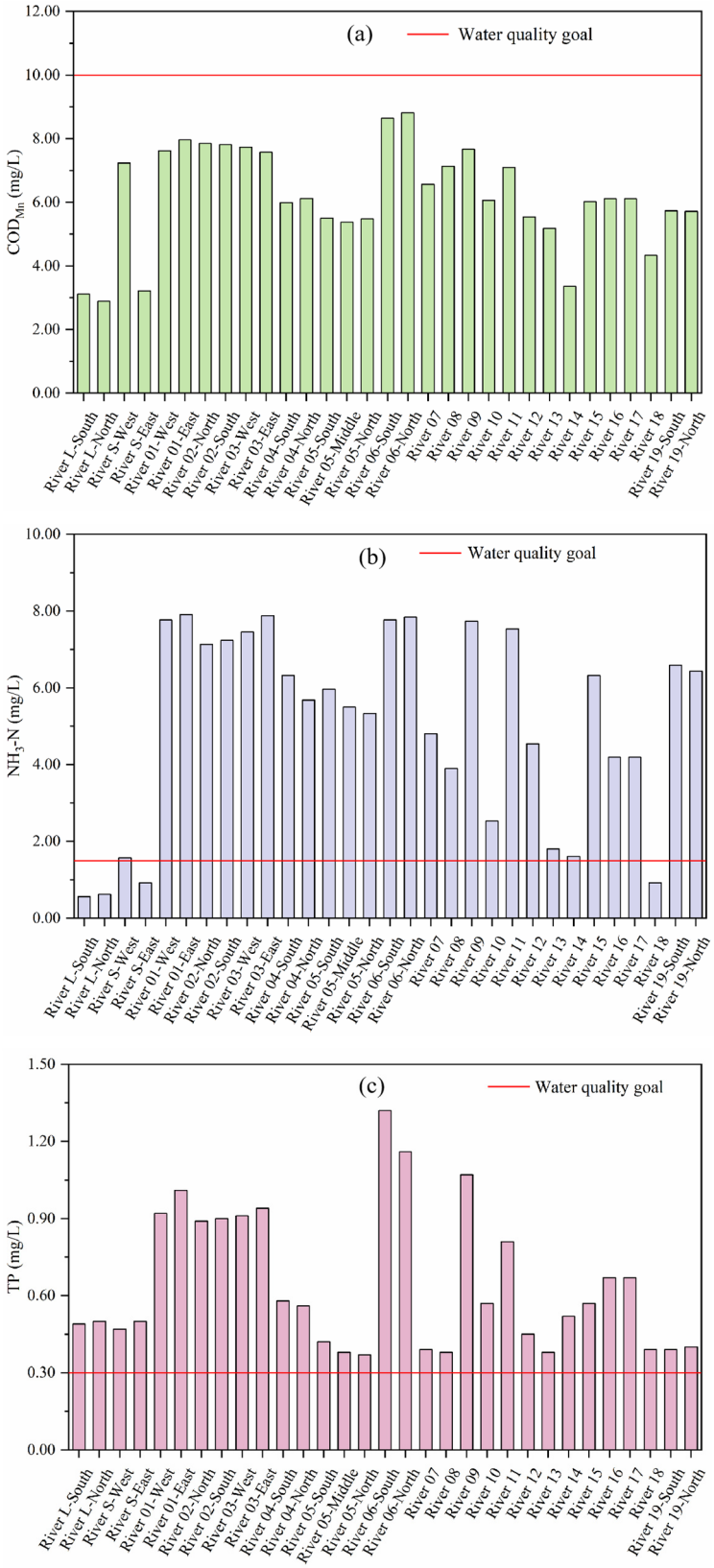


Figure 2. The initial concentrations of (**a**) COD, (**b**) NH_3-N, and (**c**) TP of the receiving rivers.

Based on the above analysis of the initial water quality in the rivers, considering the characteristics of the wastewater treatment plant and the water quality evaluation requirements proposed in this study, and allowing for a certain margin for external pollution, the

concentrations of conventional pollutants in the reclaimed water are adjusted appropriately. NH_3-N and TP are set at 1.5 mg/L and 0.3 mg/L, respectively, following the Class IV surface water requirements, and COD_{Mn} is set at 6 mg/L in accordance with the Class III surface water requirement.

Meanwhile, due to the differences in water replenishment schemes and water system conditions, different ecological restoration and algal bloom risk control measures should be adopted for the eco-restoration section of the reclaimed water in River L and the redesign of the area near River 02. Based on the relevant conclusions of this study and referencing the construction experience of River L, an analysis of the hydrological conditions of the surrounding rivers was conducted starting from the water replenishment point in River 02 along the direction of the water flow. River 02 has a length of only 117 m with water depths ranging from 0.5 to 2.5 m. Before reuse, the flow velocity can reach a maximum of 2.5 m/s. When the replenishment volume reaches nearly 30 times the original water volume of the river, the flow velocity will further increase, indicating good hydrodynamics and high ecological safety. The directly connected River 01 has water depths ranging from 1 to 2 m and flow velocities from 0 to 1 m/s, while River 03 has water depths ranging from 0 to 3 m and flow velocities from 0 to 1 m/s. The replenishment volume can also reach about twice the original water volume, resulting in a relatively low risk of algal bloom. Moving outward, River 09 and River 19 have shorter lengths and higher flow velocities, while River 04 and River 06 have longer lengths and slower flow. Before replenishment, the flow velocities in River 04 and River 06 are only between 0 and 0.3 m/s and 0 and 0.5 m/s, respectively. With the dispersion of the replenishment volume, the improvement in hydrodynamics is only moderate. Therefore, the design of the ecological restoration section and the control of algal bloom risks focus on River 04 and River 06. Building upon the improved hydrodynamics, nitrogen and phosphorus nutrients in the water will be reduced by planting submerged plants. If necessary, water quality purification and algae inhibition measures can be implemented in River 01 and River 03 to further reduce the risk of algal blooms.

3.2. Model Simulation of Reclaimed Water Replenishment Scheme

The water quality of 21 urban rivers after implementing the reclaimed water replenishment and the joint operation of the water gate and pump stations are simulated using MIKE11, as shown in Figures 3 and S3–S5. After 7 days of reclaimed water replenishment, the water quality in each river has improved to varying degrees. Among them, Rivers 01, 02, 03, 04, 06, 09, and 19, particularly in the southern areas (near River 01), show the most significant improvement, reaching around 90%. In River 05, except for the southern end, the improvement in NH_3-N exceeds 70%. For Rivers 07 and 08, NH_3-N and COD_{Mn} have improved by approximately 55% and 90%, respectively. As for Rivers 15, 16, and 17, the improvement in NH_3-N and TP is around 50%.

Except for River S in the east, which has a COD_{Mn} concentration of 4.03 mg/L, almost all other river sections have a COD_{Mn} concentration of 6.00 mg/L, which is consistent with the water quality of the reclaimed water used for replenishment. The COD_{Mn} concentration is close to the requirements of Class III surface water, and the compliance rate with Class IV water quality standards is 100%. As for NH_3-N concentration, the compliance rate relative to Class IV surface water has increased to 35.5%, and the rate relative to Class V water has reached 58.1%. For TP concentration, the compliance rate relative to Class IV surface water has increased to 35.5%, and the rate relative to Class V water has reached 87.1%. Comparing the water quality after replenishment with the original conditions, it is evident that there is a significant consistency in pollutant concentrations. This indicates that the water hydrodynamics in the river network have been effectively improved, leading to increased rates of pollutant mixing and dispersion. River sections in the south of River 05, River 11, River 10, and the north of River 19, which are located at the boundaries of the river network simulation map and are far from the replenishment point, show relatively minor changes in water quality. However,

the problem of nitrogen and phosphorus exceeding the standard is still evident in these areas. Further measures may be required to address this issue.

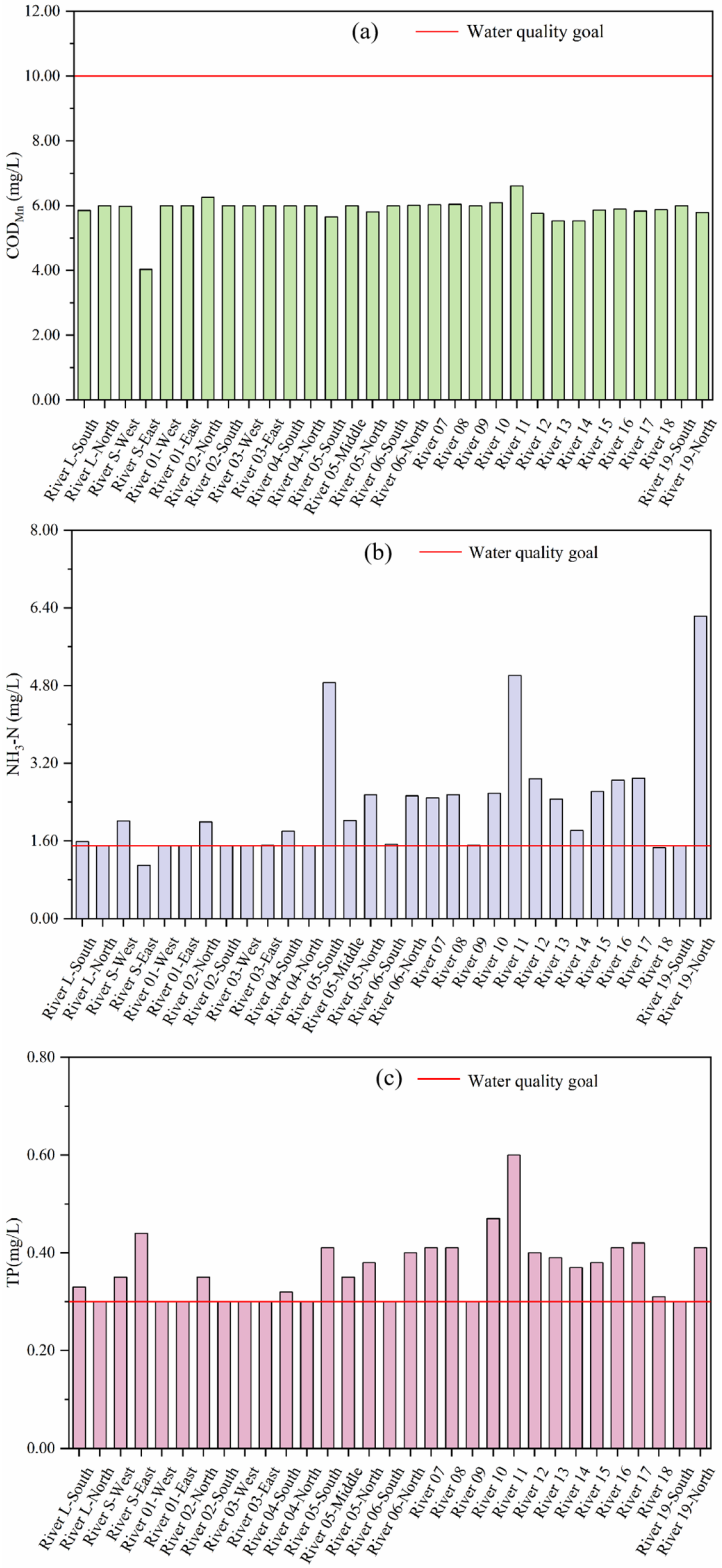


Figure 3. Simulated results of the concentrations of (**a**) COD, (**b**) NH_3-N, and (**c**) TP in the targeted receiving river after 7 days of water supplementation.

Under the joint scheduling of river hydraulic facilities and large-scale of reclaimed water reuse, the basic water quality indicators COD_{Mn}, NH_3-N, and TP in the river network have shown significant improvement, and the hydrodynamics of the rivers have been significantly enhanced. As many studies have proven, the ecological and water quality conditions of the receiving water body for reclaimed water reuse are closely linked to its baseline conditions, reclaimed water quality, and other relevant factors. Relying solely on reclaimed water to enhance river water quality and aquatic ecosystems is insufficient, so it is necessary to implement in situ ecological restoration measures to further purify water quality and improve the aquatic ecosystem [30,31]. Building on these improvements, the implementation of ecological restoration measures including submerged plant cultivation in key river sections can further purify the water quality, promote the attainment of water environmental quality standards in corresponding functional zones of the river, and reduce the risk of algal blooms.

It is worth mentioning that the application of MIKE11 modeling software in this study is valuable for assessing large-scale reclaimed water reuse in urban rivers. However, it comes with some limitations. The model simplifies complex natural processes, relies on input data quality, and makes assumptions about steady-state conditions, which may not fully capture the dynamic nature and variability of real-world urban river systems. Additionally, the study does not account for external factors like rainfall and pollution, which can significantly influence water quality. These limitations should be acknowledged to provide a more complete understanding of the MIKE11 model's suitability and its implications for real-world applications.

3.3. Scheme Evaluation

Using the comprehensive water quality assessment method developed in this study for reclaimed water reuse in river channels, a detailed analysis of the large-scale reclaimed water reuse project was conducted, resulting in comprehensive evaluation scores and grades as shown in Table S3. Since all the reclaimed water originates from the same wastewater treatment plant, the evaluation of the production process is the same as for the field experiment of reclaimed water reuse in River L. The calculated comprehensive score for the primary indicators is 92. Following the joint scheduling scheme and 7 days of replenishment, there was a significant improvement in river water quality and a notable enhancement in river network hydrodynamics. The calculated comprehensive score for the primary indicator of river water quality compliance is 86, and the calculated comprehensive scores for the primary indicators of algal bloom risk in the river and river hydrodynamics are both 92.

The correlation degrees of evaluated indicators are calculated as shown in Figure 4. Except for the primary indicators of river water quality compliance, which are at Level II, all other secondary indicators are at Level I. The overall score of the large-scale water reuse engineering scheme reaches 89, approaching Level I. The comprehensive scores of the four primary indicators range between 86 and 92, indicating that the overall plan is relatively scientific and reasonable. The reuse scheme is capable of effectively controlling the occurrence of algal blooms with the help of submerged plants and hydraulic regulation while ensuring the safety of water functional zones and meeting the requirements of various departments. The proposed plan may be utilized as a guideline for the implementation of practical recycling projects.

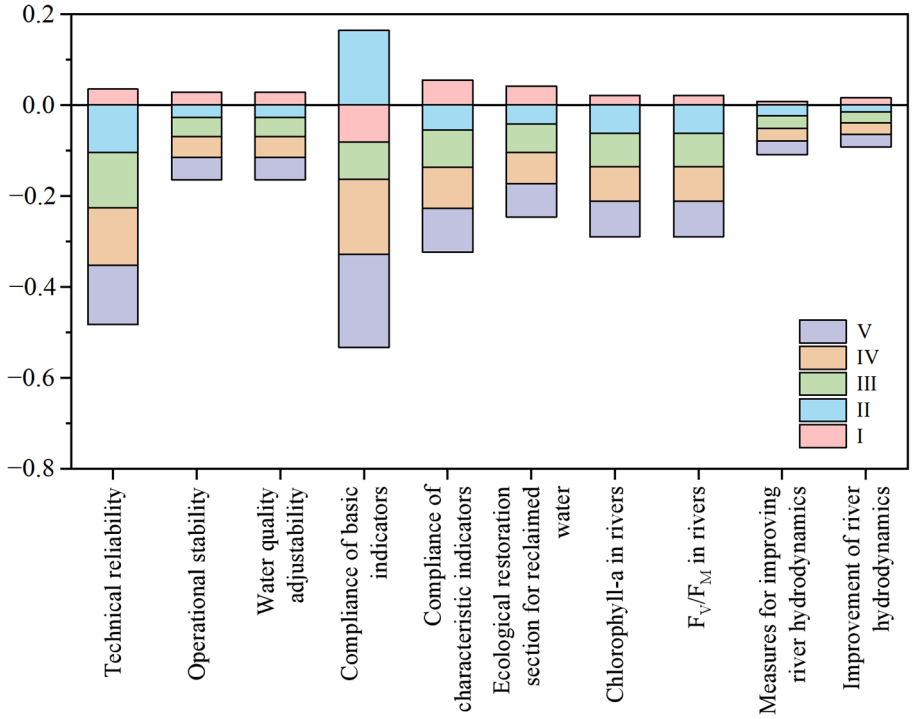


Figure 4. The correlation degrees of evaluated indicators.

In the evaluation method, the primary focus is on assessing the technical feasibility, water quality stability, and ecological impacts of large-scale reclaimed water reuse in urban river restoration. However, it is essential to recognize that in practical engineering applications, ethical and ecological concerns can play a crucial role in influencing the success and acceptance of such projects. Public opinion and community acceptance are vital factors that can significantly impact the implementation of these projects. Additionally, ecological concerns should be addressed, as introducing reclaimed water into river ecosystems may have unforeseen consequences on aquatic habitats, biodiversity, and overall ecological health. These factors are essential to ensure the sustainable and ethical use of reclaimed water in urban river restoration. As research progresses, it is imperative to broaden the focus and conduct further studies that delve deeper into the ethical and ecological aspects of reclaimed water reuse in urban river projects. By addressing these concerns and incorporating them into our evaluation criteria, a more comprehensive and well-rounded approach that not only ensures technical feasibility but also respects ethical considerations and safeguards ecological integrity can be developed and applied. This holistic perspective will help guide the implementation of practical recycling projects and contribute to the overall success and acceptance of such initiatives.

4. Conclusions

This study explored the feasibility of large-scale reclaimed water reuse in urban rivers as a sustainable solution to address water resource challenges and promote ecological restoration. Through MIKE11 modeling software, the water quality improvements resulting from the implementation of the reclaimed water replenishment scheme were simulated, and a comprehensive evaluation method utilizing the physical element extension– AHP evaluation model was developed to assess the efficiency and feasibility of the large-scale project. The simulation results showed significant improvements in water quality indicators, particularly in COD_{Mn}, NH_3-N, and TP concentrations, in the receiving urban rivers. The hydrodynamics of the river network were effectively enhanced, and pollutant mixing and dispersion rates increased, contributing to the observed water quality improvements. The combination of large-scale reclaimed water reuse and the joint operation of water gates and pump stations played a vital role in achieving these positive outcomes. The comprehen-

sive evaluation demonstrated that the proposed large-scale reclaimed water reuse project reached an overall score of 89, approaching Level I, which indicates a highly scientific and reasonable plan. The project is able to effectively control the risk of algal blooms, ensure the safety of water functional zones, and meet the requirements of various management authorities. This work provides essential insights for guiding the implementation of similar reclaimed water reuse projects in other urban river systems.

Furthermore, policymakers should prioritize the promotion of large-scale reclaimed water reuse in urban rivers to address water scarcity and promote ecological restoration. This can be achieved by establishing stringent water quality standards, encouraging advanced hydrological modeling and comprehensive evaluation methods, and emphasizing the importance of ecological restoration measures. Additionally, raising public awareness and fostering interagency collaboration are key to the successful implementation of such projects, contributing to sustainable urban water management and environmental resilience.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/w15223909/s1, Table S1. The initial water quality of the receiving rivers; Table S2. The environmental quality standard for surface water in China (GB3838-2002 [32]); Table S3. The calculation of correlation degrees and scores of evaluated indicators; Figure S1. The cross-sections of representative rivers in the project; Figure S2. The tide of River YJ in July; Figure S3. Simulated COD concentrations distribution map after 7 days of water replenishment; Figure S4. Simulated NH_3-N concentrations distribution map after 7 days of water replenishment; Figure S5. Simulated TP concentrations distribution map after 7 days of water replenishment; Text S1. Calculation of indicator weights.

Author Contributions: Conceptualization, X.L., D.S. and L.Z.; methodology, X.L. and J.X.; software, X.L. and L.Z.; validation, X.L. and J.X.; formal analysis, X.L.; resources, W.Z., S.L. and J.X.; data curation, X.L.; writing—original draft preparation, X.L., S.L. and D.S.; writing—review and editing, X.L., D.S., W.Z. and J.X.; visualization, X.L.; supervision, J.X. and Z.L.; project administration, H.F., W.Z. and J.W.; funding acquisition, S.L., H.F. and J.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was supported by the scientific program of PowerChina Huadong Engineering Corporation Limited (KY2018-SHJ-02 and KY2022-HS-02-20).

Data Availability Statement: All relevant data are included in the paper or its Supplementary Information.

Conflicts of Interest: Authors X.L., S.L., W.Z., J.W. and H.F. are employed by the company PowerChina Huadong Engineering Corporation Limited. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Li, Q.; Wang, W.; Jiang, X.; Lu, D.; Zhang, Y.; Li, J. Analysis of the potential of reclaimed water utilization in typical inland cities in northwest China via system dynamics. *J. Environ. Manag.* **2020**, *270*, 110878. [CrossRef]
2. Liao, Z.; Chen, Z.; Wu, Y.; Xu, A.; Liu, J.; Hu, H.-Y. Identification of development potentials and routes of wastewater treatment and reuse for Asian countries by key influential factors and prediction models. *Resour. Conserv. Recycl.* **2021**, *168*, 105259. [CrossRef]
3. Padowski, J.C.; Gorelick, S.M. Global analysis of urban surface water supply vulnerability. *Environ. Res. Lett.* **2014**, *9*, 104004. [CrossRef]
4. Yin, X.-A.; Yang, Z.; Zhang, E.; Xu, Z.; Cai, Y.; Yang, W. A New Method of Assessing Environmental Flows in Channelized Urban Rivers. *Engineering* **2018**, *4*, 590–596. [CrossRef]
5. Wolfand, J.M.; Taniguchi-Quan, K.T.; Abdi, R.; Gallo, E.; Irving, K.; Philippus, D.; Rogers, J.B.; Stein, E.D.; Hogue, T.S. Balancing water reuse and ecological support goals in an effluent dominated river. *J. Hydrol. X* **2022**, *15*, 100124. [CrossRef]
6. Zabala, J.A.; Dolores de Miguel, M.; Martinez-Paz, J.M.; Alcon, F. Perception welfare assessment of water reuse in competitive categories. *Water Supply* **2019**, *19*, 1525–1532. [CrossRef]
7. Lv, X.; Zhang, J.; Liang, P.; Zhang, X.; Yang, K.; Huang, X. Phytoplankton in an urban river replenished by reclaimed water: Features, influential factors and simulation. *Ecol. Indic.* **2020**, *112*, 106090. [CrossRef]

8. Sun, D.; Lin, X.; Lu, Z.; Huang, J.; Li, G.; Xu, J. Process evaluation of urban river replenished with reclaimed water from a wastewater treatment plant based on the risk of algal bloom and comprehensive acute toxicity. *Water Reuse* **2022**, *12*, 1–10. [CrossRef]
9. Maryam, B.; Buyukgungor, H. Wastewater reclamation and reuse trends in Turkey: Opportunities and challenges. *J. Water Process Eng.* **2019**, *30*, 100501. [CrossRef]
10. Radcliffe, J.C.; Page, D. Water reuse and recycling in Australia—History, current situation and future perspectives. *Water Cycle* **2020**, *1*, 19–40. [CrossRef]
11. Ren, J.; Han, G.; Liu, X.; Liu, J.; Gao, X. Water Chemical Characteristics and Water Quality Evaluation of the River under the Ecological Water Replenishment: A Case Study in the Yongding River Basin in North China. *ACS Earth Space Chem.* **2023**, *7*, 1505–1515. [CrossRef]
12. Yu, Y.; Song, X.; Zhang, Y.; Zheng, F.; Liang, J.; Liu, L. Identifying spatio-temporal variation and controlling factors of chemistry in groundwater and river water recharged by reclaimed water at Huai River, North China. *Stoch. Environ. Res. Risk Assess.* **2014**, *28*, 1135–1145. [CrossRef]
13. Zheng, F.; Liu, L.; Li, B.; Yang, Y.; Guo, M. Effects of Reclaimed Water Use for Scenic Water on Groundwater Environment in a Multilayered Aquifer System beneath the Chaobai River, Beijing, China: Case Study. *J. Hydrol. Eng.* **2015**, *20*, B5014003. [CrossRef]
14. Li, J.; Sun, Y.; Wang, X.; Xu, S. Changes in Microbial Community Structures under Reclaimed Water Replenishment Conditions. *Int. J. Environ. Res. Public Health* **2020**, *17*, 1174. [CrossRef] [PubMed]
15. An, S.; Song, Y.; Fu, Q.; Qi, R.; Wu, Z.; Ge, F.; Lu, X.; An, W.; Han, W. Reclaimed water use improved polluted water's self-purification capacity--Evidenced by water quality factors and bacterial community structure. *J. Clean. Prod.* **2023**, *386*, 135736. [CrossRef]
16. Singh, N.K.; Gupta, G.; Upadhyay, A.K.; Rai, U.N. Biological Wastewater Treatment for Prevention of River Water Pollution and Reuse: Perspectives and Challenges. In *Water Conservation, Recycling and Reuse: Issues and Challenges*; Singh, R.P., Kolok, A.S., Bartelt-Hunt, S.L., Eds.; Springer: Singapore, 2019; pp. 81–93.
17. Xing, L.; Kong, M.; Xie, X.; Sun, J.; Wei, D.; Li, A. Feasibility and safety of papermaking wastewater in using as ecological water supplement after advanced treatment by fluidized-bed Fenton coupled with large-scale constructed wetland. *Sci. Total Environ.* **2020**, *699*, 134369. [CrossRef]
18. Arrington, D.A.; Harris, R.J.; Layman, C.A.; Gomes, D.G.E. Leveraging green infrastructure for efficient treatment of reclaimed water. *Sci. Total Environ.* **2023**, *872*, 162232. [CrossRef] [PubMed]
19. Mano, H.; Takeda, F.; Kitamura, T.; Okamoto, S.; Suzuki, Y.; Park, C.-B.; Yasui, N.; Kobayashi, K.; Tanaka, Y.; Yamashita, N.; et al. Water quality comparison of secondary effluent and reclaimed water to ambient river water of southern Okinawa Island via biological evaluation. *Environ. Monit. Assess.* **2017**, *189*, 442. [CrossRef] [PubMed]
20. Pan, W.; Huang, Q.; Huang, G. Nitrogen and Organics Removal during Riverbank Filtration along a Reclaimed Water Restored River in Beijing, China. *Water* **2018**, *10*, 491. [CrossRef]
21. Prat, N.; Rieradevall, M.; Barata, C.; Munne, A. The combined use of metrics of biological quality and biomarkers to detect the effects of reclaimed water on macroinvertebrate assemblages in the lower part of a polluted Mediterranean river (Llobregat River, NE Spain). *Ecol. Indic.* **2013**, *24*, 167–176. [CrossRef]
22. Deng, S.; Yan, X.; Zhu, Q.; Liao, C. The utilization of reclaimed water: Possible risks arising from waterborne contaminants. *Environ. Pollut.* **2019**, *254*, 113020. [CrossRef]
23. Lin, X.; Xu, J.; Keller, A.A.; He, L.; Gu, Y.; Zheng, W.; Sun, D.; Lu, Z.; Huang, J.; Huang, X.; et al. Occurrence and risk assessment of emerging contaminants in a water reclamation and ecological reuse project. *Sci. Total Environ.* **2020**, *744*, 140977. [CrossRef] [PubMed]
24. Zhang, R.; Zhang, Y.; Liu, L.; Wang, Y.; Song, Z.; Wang, X.; Liu, C.; Li, Y.; Meng, W.; Zhou, Y.; et al. Occurrence and risk assessment of heavy metals in an urban river supplied by reclaimed wastewater. *Water Environ. Res.* **2020**, *92*, 1888–1898. [CrossRef] [PubMed]
25. Heng, B.; Zhang, R.; Wang, Z.; Zhang, Y.; Wang, Y.; Song, Z.; Liu, C.; Sun, D.; Qi, F. Occurrence and risk assessment of volatile halogenated disinfection by-products in an urban river supplied by reclaimed wastewater. *Ecotoxicol. Environ. Saf.* **2021**, *211*, 111912. [CrossRef] [PubMed]
26. Yu, Y.; Sun, D.; Zheng, T.; Cheng, W.; Lu, Z.; Lu, L.; Huang, J.; Xu, J. Ecological restoration effect and safety evaluation of reclaimed water from sewage treatment plant for urban rivers. *Environ. Eng.* **2021**, *39*, 1–5.
27. Akhoundi, A.; Nazif, S. Sustainability assessment of wastewater reuse alternatives using the evidential reasoning approach. *J. Clean. Prod.* **2018**, *195*, 1350–1376. [CrossRef]
28. Yang, Y.; Tang, J.; Duan, Y.; Qu, Y.; Sun, F.; Li, Z. Study on the Relationship between Different Wastewater Treatment Technologies and Effluent Standards in Jilin Liaohe River Basin Based on the Coupled Model of AHP and Fuzzy TOPSIS Method. *Sustainability* **2023**, *15*, 1264. [CrossRef]
29. Tian, K.; Liu, X.; Wang, H.; Ning, S.; Dong, Z.; Qin, X.; Zhang, L. Application of MIKE11 Model in Water Quality Improvement for Shiwuli River in Hefei. *J. China Hydrol.* **2019**, *39*, 18–23.
30. Wang, X.; Xu, S.; Tao, W.; Guo, M. Ecological restoration project of water quality in urban river supplied with reclaimed water and its efficiency analysis. *Chin. J. Environ. Eng.* **2018**, *12*, 2132–2140.

31. Zhu, L.; Lin, X.; Li, S.; Sun, D.; Fang, H.; Xu, J.; Huang, J.; Li, G. Effect and Mechanism of Applying *Myriophyllum Verticillatum* for Reclaimed Water Purification in Urban Rivers. *Water* **2023**, *15*, 2331. [CrossRef]
32. *GB3838-2002*; Environmental Quality Standards for Surface Water. Ministry of Ecology and Environment of the People's Republic of China: Beijing, China, 2002.

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