Ecological Remediation Technology of Urban Landscape Water Body

SUN Xiangxuan, XIONG Qingqing, XIAO Shizhen*

(School of Karst Science, Guizhou Normal University/State Engineering Technology Institute for Karst Desertification Control, Guiyang, Guizhou 550001, China)

Abstract Urban landscape water body is not only an important part of urban landscape construction, but also an important way to maintain landscape diversity and biodiversity, carrying the beautiful yearning of urban residents for natural life. A good state of urban landscape water body is crucial to the ecological environment of the city. However, due to the poor kinetic energy of urban landscape water body and the influence of various human factors, the quality of urban landscape water body often declines, and urban population is threatened by water security problems. Through the study of several water body ecological remediation technologies, relevant suggestions are put forward, in order to provide a reference for water pollution restoration and treatment in urban human settlement environment.

Keywords Urban landscape water body, Water body treatment, Ecological remediation

DOI 10.16785/j.issn 1943-989x.2024.1.013

With the acceleration of urbanization, urban waterscape has become an important part of modern urban spatial planning. Urban landscape water body mainly consists of artificial lakes, rivers, wetlands, as well as fountains, ponds and other artificial water landscape[1]. As an important part of urban green space, landscape water body has irreplaceable recreational functions and ecosystem service functions. In addition to controlling climate, protecting water resources, enhancing ecological diversity, promoting urban water resources recycling and improving environmental comfort, landscape water body can also discharge floodwater and control soil erosion[2]. However, due to the limitations of urban landscape water body and unreasonable design, the biodiversity of urban landscape water body is usually lower than that of natural water bodies, which further results in the decline of the quality of urban landscape water body and adversely affects urban landscape[3]. As an ecological restoration technology, water body ecosystem remediation and construction has been widely applied in various fields, such as urban domestic sewage treatment, parks, residential areas and urban river ecological construction. It not only is conducive to improving the water environment and enhancing the vitality of urban ecosystem, but also can effectively protect biodiversity and promote the self-purification ability of water bodies, thus creating a healthier and livable urban environment and improving the quality of life of residents.

1 Research overview

At present, physical technology, chemical technology and bioremediation technology are the main water body treatment technologies used in actual work[4]. The main treatment measures of physical technology include sewage interception, physical precipitation, channel cleanout, dredging, oxygenation and aeration, etc., which can quickly improve water quality and effectively reduce water pollution in a short period of time. However, these management measures usually require a large amount of engineering investment, but only treat symptoms rather than the root cause. In addition, these physical technologies may also damage the water ecosystem during the implementation process, thus affecting the habitat environment of aquatic animals and plants. There are two types of chemical techniques: chemical algae removal and chemical fixation. Chemical algae removal is a relatively simple method with remarkable effect, and can quickly reduce the number of algae in the water by adding specific chemical agents, thus achieving rapid improvement of water quality. Chemical fixation can quickly reduce the degree of pollution by using chemical agents to oxidize or precipitate pollutants in the water body. However, the use of chemical agents may cause secondary pollution of water body. Bioremediation technology mainly includes ecological floating island, constructed wetland, biological manipulation and microbial restoration. By introducing a variety of microorganisms, aquatic animals and plants with strong purification and anti-pollution, bioremediation technology maintain the balance and stability of the system from the ecosystem, and restore the ecological function of landscape water body and its purification effect, so as to achieve the goal of purifying water quality. Compared with physical and chemical means, bioremediation technology has a more lasting and safer treatment effect. The concept emphasizes that ecological remediation is mainly based on the self-regulation ability of the ecosystem itself, supplemented by artificial auxiliary measures.

2 Research progress

Ecological remediation is a virtuous cycle of making full use of biotechnology to improve the ecological function of the system and gradually realizing self-maintenance and self-coordination of the system[5]. The concept of ecological remediation was first proposed in the 1830s, and was systematically researched after the publication of the *Restoration Process of Damaged Ecosystems* edited by Cairns in 1980. Japanese scholars hold that ecological remediation refers to the restoration, reconstruction and enhancements of damaged systems, which is similar to the concept of "ecological restoration" proposed by European and American scholars[6]. China is also a country with earlier ecological remediation research. In 1973, China formulated the first comprehensive regulation on environmental protection—*Several Provisions on the Protection and Improvement of the Environment* (*Draft for Trial Implementation*). Chinese scholar Jiao Juren suggests that in order to restore the damaged ecosystem faster, in addition to implementing natural protection, we can also use artificial auxiliary measures to serve the healthy operation of the ecosystem, and the accelerated restoration is called ecological remediation[7].

2.1 Basic characteristics

Landscape water body ecological remediation technology has certain differences in basic concept, mechanism of action, structural

Received: December 15, 2023 Accepted: February 3, 2024

Sponsored by Guizhou Provincial Key Technology R&D Program (220 2023 QKHZC).

* Corresponding author.

composition and application form. Each water body ecological remediation technology has its own characteristics, as shown in Table 1.

2.2 Research and application

2.2.1 Constructed wetland technology. Zhang Jiayao et al.[8] selected reed and water oat to construct a subsurface flow constructed wetland sewage treatment system for nitrogen removal. The results showed that the total nitrogen removal rate of reed system was 49.34%, higher than that of water oat system (45.49%), and the total nitrogen removal rate of plant-free system was the lowest of 38.69%, indicating that the total nitrogen removal rate of plant-introduced system is better than that of plant-free system. Yan Li et al.[9] compared the purification effects of single-grade and third-grade constructed wetlands on eutrophic water body, and the results showed that third-grade constructed wetlands had better nitrogen and phosphorus removal performance than single-grade constructed wetlands, but both had better effects on the removal of organic matter, turbidity and blue-green algae.

2.2.2 Ecological floating island technology. Wu Jianqiang et al.[10] established an eutrophic plant floating bed experiment project, and selected *Thalia dealbata*, *Canna indica*, *Iris pseudacorus* and *Lythrum salicaria* to test the absorption capacity of nitrogen and phosphorus. The results showed that the nitrogen and phosphorus absorption capacity of *C. indica* and *T. dealbata* were higher than that of *I. pseudacorus* and *L. salicaria*, and *I. pseudacorus* had the lowest nitrogen and phosphorus absorption capacity. Among them, *T. dealbata* had the highest absorption of nitrogen, and *C. indica* had the highest absorption of phosphorus. Chen Maohua[11] carried out in-situ restoration experiments on landscape water body with perennial *Chrysopogon zizanioides* seedlings, and found that the removal rates of total phosphorus and chemical oxygen demand by ecological floating bed were 28.10%–51.06% and 19.95%–51.15%, while the concentration of dissolved oxygen increased by 2.75%–137.85%, indicating that *C. zizanioides* had certain effect on adsorption of ammonia nitrogen, total phosphorus and chemical oxygen demand in water.

2.2.3 Aquatic animal management technology. Currently, the widely used methods for aquatic animal regulation include fish, benthic animals and combined regulation[12]. Li Jiamin et al.[13] conducted multiple water treatment tests with different combinations of biological chains, and found that the combination test of " silver carp and bighead carp + canna + benthos + biological filler" reached the best effect, with total phosphorus and total nitrogen reduced by more than 85%, ammonia nitrogen decreased by 78%, COD_{Mn} decreased by 66%, and chlorophyll a decreased by 85.59%, which was significantly higher than other experimental groups with shorter biological chains. It also showed that the more complete the biological chain, the better the effect of controlling the number of algae and nutrient concentration in the water. Xiao Xiaoyu et al.[14] selected *Nymphaea tetragona*, *Hydrilla verticillata*, *Aristichthys nobilis* and *Cipangopaludina chinensis* to conduct a combined test for water body purification. The experimental results showed that the combination of *N. tetragona* and *H. verticillata* had the most outstanding removal efficiency of total phosphorus and total nitrogen, while the combination of *N. tetragona*, *H. verticillata*, *A. nobilis* and *C. chinensis* could effectively inhibit the growth of algae and maintain the minimum chlorophyll a content. Therefore, the eutrophication of landscape water body can be effectively improved by the combination of *N. tetragona*, *H. verticillata*, *A. nobilis* and *C. chinensis*.

2.2.4 Microbial treatment technology. Cao Jingguo et al.[15] used the main degrading bacteria composed of nitrifying bacteria, yeast and photosynthetic bacteria, and the auxiliary degrading bacteria composed of *Bacillus subtilis* and lactic acid bacteria to remove organic matter and ammonia nitrogen in the water body. Wang Shengli et al.[16] screened 1,351 species of native strains through the investigation of microbial resources in Baiyangdian, established the microbial population bank of Baiyangdian, and developed a series of native functional strains for improvement and water quality control such as nitrogen removal, phosphorus removal and denitrification. Ma Ying et al.[17] built a treatment system of "substrate improvement+water quality control+biological filter dam+biological rope filler+micro-nano aeration system" based on microbial carrier technology, and carried out ecological remediation and treatment of farmland ditches. The water

Table 1 Characteristics of ecological remediation technology

Technology item	Basic concept	Mechanism of action	Structural composition	Application form
Constructed wetland	An artificially designed and constructed complex composed of substrate, aquatic hygrophytes, aquatic animals, and water bodies by simulating natural wetlands	Constructed wetlands purify sewage by means of filtration, sedimentation and biodegradation through soil, water and biological action in wetland ecosystem	Filler, substrate, aquatic plant, etc.	Free surface flow type, horizontal subsurface flow type, vertical flow type
Ecological floating island	A water surface planting technology using polymer material as the floating carrier and planting substrate	Plant roots play a role of absorbing nutrients such as nitrogen and phosphorus, releasing oxygen into water, secreting special chemicals, and promoting nitrification and denitrification reactions of microorganisms in the root zone	Frame, carrier, substrate, aquatic plant, etc.	Dry floating island, wet floating island
Aquatic animal management	A treatment technology that regulates the quantity and density of various aquatic organisms according to the competition of the aquatic food chain and uses aquatic animals to absorb organic matter, inorganic matter and algae in water	Aquatic animals are used to absorb organic matter, inorganic matter, algae and so on	Zooplankton, benthonic animal, etc.	–
Microbial treatment	A biotechnology for water purification by using specific microbial inoculants	Special microorganisms decompose organic pollutants in water, remove foul-smelling pollutants such as sulfur and nitrogen, and inhibit the growth of harmful microorganisms and algae	Special microorganism	CBS technology, EM technology
Biofilm treatment	A method of organic sewage treatment by attaching microorganisms that grow on the surface of some solid objects	The organic matter in the water is absorbed and decomposed by the outer layer of aerobic bacteria, and carried out anaerobic decomposition in the anaerobic layer to achieve the goal of removing organic pollutants in the water	Attached carrier, hanging structure, water microorganism, etc.	Natural material carrier, polymer synthetic material carrier
Stabilization pond treatment	A general term for the structure that uses the natural purification capacity to treat sewage	The process of water purification is similar to that of natural water body, and artificial technical means are used to improve and accelerate the purification process of water body	Pond, impermeable layer, microorganism, aquatic plant, etc.	Aerobic, anaerobic, facultative

quality index detection showed that the removal rates of COD, NH_3-N and TP were about 8.30%, 61.24% and 57.77%, respectively, indicating that the ecological governance system had remarkable remediation effect.

2.2.5 Biofilm treatment technology. The substantive research and application of biofilm technology began from the study on remediation of polluted river water by biofilm growing on pebbles[18]. At present, the main biofilm technologies are gravel contact oxidation method and artificial filler contact oxidation method. Jin Zhujing et al.[19] used bionic filler as the carrier to combine artificially inoculated bacteria species and aerated oxygenation in a heavily polluted river channel at north bank of Dianehi Lake. In the dry season, the average removal rates of COD, BOD and TN by this technology were 40.1%, 40.0% and 13.5%, but rainy season had a great impact on this technology. Moreover, the technology mainly focuses on the removal of COD and BOD, and still needs to be improved when considering the removal effect of total nitrogen and ammonia nitrogen.

2.2.6 Stabilization pond treatment technology. Zhao Limin et al.[20] combined a variety of functional ponds to build a biological stabilization pond system in order to deal with the problems of black and odorous water and serious water bloom in Daqing River along the Dianchi Basin. The removal rates of TN, TP, NH_4^+-N, BOD_5 and COD in the pond system reached 29.29%, 48.68%, 33.68%, 68.14% and 71.25%, respectively, indicating that biological stabilization pond system is an effective sewage treatment system and can provide ecological restoration technical support for similar river pollution.

3 Discussion

The pollution sources of urban landscape water bodies are diverse and complex, including the release of internal pollution in water body, natural pollution and man-made pollution from outside water body, and the pollution substances include organic pollution, inorganic salt pollution and heavy metal pollution[21-22]. Ecological remediation technology will be affected by various factors in the process of water ecological environment treatment, and the current ecological remediation technology also has certain defects and deficiencies.

3.1 Influencing factors of constructed wetland

Constructed wetlands have low cost of ecosystem construction and management, simple maintenance, good ecological effects, landscaping and other added values, and are now widely used in clean management and lake ecological restoration[23]. However, the plants used in constructed wetlands often produce large amounts of biomass, which can lead to clogging and increase operating and maintenance costs. Seasonal changes also have a significant impact on the performance of constructed wetlands, with higher efficiency in summer and lower efficiency in winter. In addition, constructed wetlands are relatively ineffective in treating toxic and high-concentration wastewater.

3.2 Influencing factors of ecological floating island

There are many problems to be solved in the research and practical application of ecological floating island technology. The floating island materials currently used have unsatisfactory wind and wave resistance, firmness and corrosion resistance. For example, foam board, plastic block and other materials have poor bearing capacity and can not be reused; plant rhizomes in ecological floating islands are prone to rot, and there is a risk of re-polluting the water body if not treated in time. At present, there are few researches on ecological floating island technology in cold areas, and the suitable plant selection and planting technology need to be further explored and studied. The corresponding technical system has not been established in the practical application of ecological floating island. For example, how to establish plant community landscape, late maintenance of plants, complete and feasible supporting infrastructure, and research and development of new floating island materials are all important factors affecting the breakthrough development of ecological floating island technology.

3.3 Biological influence relationships of aquatic animals

Aquatic animal community regulation plays an important role in the process of water body ecological restoration, but a single aquatic animal regulation measure has its limitations. In the future research work, the relationship between biological populations must be considered, mainly because the species and quantity of organisms in the water body will affect the variation of the population and quantity of other organisms, and have an adverse impact on the stability of biological systems in the water body. In future studies, it is necessary to further investigate the relationship among aquatic animals, aquatic plants and microorganisms to build a complete and stable water ecosystem.

3.4 Microbial safety and efficient strain screening

Although microbial remediation technology has been applied to the actual sewage treatment, the use of microbial agents to treat polluted water bodies still needs to consider environmental adaptability, biosafety and other issues. And the combination of microbial flora, reasonable formulation of bio-stimulants, application of high density fermentation technology, maintenance of microbial activity and other factors are also crucial for the practical application effect. Meantime, the application of this technology must follow the principle of microbial physiological ecology, and strengthen the screening and optimization of microorganisms, especially the study of coordinated symbiosis between different microorganisms.

3.5 Material properties of biofilm

In the actual use of biofilm technology, due to the relatively light concentration of pollutants in the water body, there may be problems such as a small number and types of microorganisms attached to the biological carrier, and difficult formation of biofilm structure, which is mainly related to the structure and characteristics of biological attachment (carrier). At present, the biological carrier materials widely used include polyethylene (PE), polypropylene (PP), polystyrene (Ps), polyurethane (Pu), various resins, plastics, soft or semi-soft fibers, etc.[24]. However, these materials in the field of water treatment has the problem of poor hydrophilicity and biological affinity, leading to slow biofilm culturing speed, limited biofilm culturing amount, and insufficient binding degree between film and carrier filler, which limits the application of biofilm technology in sewage treatment to a large extent. Studies have shown that proper modification of these biofilm carriers can significantly improve their hydrophilicity and bioaffinity[25]. In recent years, researchers are also developing new carrier materials by improving the structure and composition of biofilm carriers, so as to overcome the drawbacks and defects of biofilm technology in repairing polluted water body, and improve the efficiency of water treatment and the level of water purification.

3.6 Structural combination of stabilization pond

Although traditional stabilization pond has the advantages of low input, low energy consumption, low treatment cost and simple operation and management, it has some disadvantages such as limited treatment load, long hydraulic retention time, wide land area, silt accumulation, groundwater pollution, odor and mosquito breeding, and the treatment effect of sewage is greatly fluctuated by seasonal changes. At present, with the deepening of research, there have been many new combined stabilization ponds, such as hydrolytic acidification+stabilization pond process, air flotation+oxidation ditch+stabilization pond process, micro-electrolysis+contact oxidation+stabilization pond process, coagulation+biofilm aeration pool+oxidation pond method, etc.

The emergence of combined process makes up for many shortcomings of stabilization pond and further improves its advantages. In the future, stabilization pond technology needs to be developed in the direction of strengthening research, improving efficiency, improving facilities, optimizing system and comprehensive utilization.

4 Suggestions and prospects

As China attaches importance to the requirements of ecological development, with constantly improving requirements for urban sustainable development and people's quality of life (including ecological quality of living environment), the water environment quality of urban landscape water body is becoming increasingly important, and the treatment of landscape water body will also become the top priority in the future water pollution control. In the treatment of urban landscape water body, we can not blindly select a certain process technology, but should select reasonable remediation technology and use different technical means to optimize the combination according to the actual situation of current water body, so as to achieve the optimal goal of water body landscape and maximize the role of urban landscape water body. The setting of urban landscape water body needs to consider environmental sustainability, water resource efficiency and ecosystem health.

References

[1] Jiang, H. T., Li, Y. L. & Li, L. (2016). Research on rational allocation of ecological water use in urban waterscape and brief analysis of problems. *Henan Water Resources & South-to-North Water Diversion*, (1), 15-16.

[2] Addo-Bankas, O., Zhao, Y. Q. & Gomes, A. et al. (2022). Challenges of urban artificial landscape water bodies: Treatment techniques and restoration strategies towards ecosystem services enhancement. *Processes*, *10*(12), 2486.

[3] Xie, X. M. (2021). Analysis on the restoration and construction of urban landscape water ecosystem. *Environmental Science Survey*, *40*(1), 59-62.

[4] Wang, J., Li, L. Y. & Liu, J. T. et al. (2021). Research progress of water ecological floating island restoration technology. *Journal of Anhui Agricultural Sciences*, *49*(20), 10-13.

[5] Xu, F. (2022). Discussion on key technical points for ecological restoration of landscape water treatment. *Inner Mongolia Water Resources*, (12), 44-46.

[6] Cao, T. T. (2019). Analysis on the technology of ecological security in Ordos Plateau region. *2019 National Academic Conference of Environmental Engineering*.

[7] Jiao, J. R. (2003). Essentials and pondering of ecological rehabilitation. *Soil and Water Conservation in China*, (2), 5-6.

[8] Zhang, J. Y., Qiu, K. M. & Xiong, K. (1999). Nitrogen removal by a subsurface flow constructed wetlands wastewater treatment system and nitrogen transformation bacteria. *Acta Scientiae Circumstantiae*, (3), 101-105.

[9] Yan, L., Chen, J. G. & He, S. B. et al. (2005). Subsurface flow type constructed wetland for purification of eutrophic scenic waters. *China Water & Wastewater*, (2), 11-13.

[10] Wu, J. Q., Wang, M. & Wu, J. et al. (2011). Study on the nitrogen and phosphorus uptake ability of four plants cultivated on floating-bed. *Environmental Science*, *32*(4), 995-999.

[11] Chen, M. H. (2022). Study on the in-situ restoration effect of ecological floating bed on landscape water bodies. *Journal of Safety and Environment*, *22*(2), 1075-1083.

[12] Sima, X. F. (2023). Research progress of aquatic animal community regulation in eutrophic water remediation. *Environmental Protection and Technology*, *29*(4), 55-59.

[13] Li, J. M., Zhang, K. F. & Chen. Y. F. et al. (2022). Control of eutrophication and algae for diversion reservoir in downstream of Yellow River by different biological chain combination. *Water Purification Technology*, *41*(1), 58-62, 82.

[14] Xiao, X. Y., Yin, L. & Long, W. W. et al. (2014). Evaluation of aquatic animals and plants on different levels of eutrophic landscape waters. *Environmental Science and Management*, *39*(6), 18-23.

[15] Cao, J. G., Jiang, Y. Z. & Jin, H. et al. (2012). Hybrid technology of microbial agent, phoslock and aquatic plant for treatment of urban landscape water. *China Water & Wastewater*, *28*(6), 65-68.

[16] Wang, S. L., Zhang, H. Y. & Yang, Q. et al. (2023). Application of in-situ ecological remediation technology guided by indigenous microorganisms in baiyangdian water pollution control project. *Environmental Engineering*, *41*(S2), 62-64.

[17] Ma, Y., Sun, P. & Xu, Z. J. et al. (2022). Construction and engineering application of canal ecological restoration and treatment based on microbial carrier technology. *Chinese Journal of Environmental Engineering*, *16*(5), 1721-1729.

[18] Lv, P. Y., Luo, J. X. & Han, Z. F. et al. (2017). Application and research progress of biofilm technology in polluted river in-situ bioremediation. *Technology of Water Treatment*, *43*(11), 1-7.

[19] Jin, J. Z., Yang, F. L. & Ye, J. L. (2012). In-situ remediation efficiency of polluted river water by biological contact oxidation process. *China Water & Wastewater*, *28*(3), 36-39.

[20] Zhao, L. M., Zhang, Y. H. & Zhang, K. N. (2013). Experimental study of river sewage treatment using biological membrane and artificial wetland technology. *South-to-North Water Transfers and Water Science & Technology*, *11*(1), 101-103.

[21] Li, X. G., Sun, Y. Y. & Huang, M. R. (2017). City water environment restoration and comprehensive governance. *Shanghai Urban Management*, *26*(4), 12-18.

[22] Xu, D., Cheng, S. P. & Fu, G. P. et al. (2006). Design of landscaping constructed wetland system for the treatment of polluted urban lakes. *China Water & Wastewater*, (12), 40-44.

[23] Zhang, X. L., Yu, Z. D. & Wang, S. et al. (2019). Research progress of pesticide removal in agricultural runoff using constructed wetlands. *Water & Wastewater Engineering*, *30*(3), 1025-1034.

[24] Zhang, F. J., Zhao, Z. Q. & Wang, S. et al. (2005). Study on treatment of wastewater by bio-film using hollow fiber membrane as carrier and bubbleless. *Journal of Jilin University* (*Earth Science Edition*), (2), 236-238.

[25] Wang, Z. Z., Li, W. Z. & Gong, W. J. (2008). Studies on anaerobic treatment of cow manure with activated carbon fiber as carrier. *Journal of Agricultural Mechanization Research*, (2), 207-210.