Measures, methods and cases of river ecological restoration

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Abstract. This work analyzed the main causes of river ecosystem degradation by summarizing the problems of river ecological environment. Second, it formulated measures and methods of river ecological restoration aiming at all kinds of ecological environment problems. In order to strengthen the pollution control and ecological environment protection, it then put forward management measures of administrative functional departments from the aspects of carrying out pipe network pollution interception, strengthening water law enforcement, pollution control of non-point sources of living and farmland, and river system control. In order to restore the degraded river ecosystem, the technical measures of ecological restoration in terms of water quantity, water quality, habitat and biodiversity were summarized. Finally, it clarified principles, steps and objectives of river ecosystem restoration, which has certain reference significance for the comprehensive and systematic restoration of river ecosystem.

1. Introduction
The report of the 19th National Congress of the Communist Party of China (CPC) regarded "ensuring harmony between human and nature" as an important part of the basic strategy of adhering to and developing socialism with Chinese characteristics in the new era, then put forward that the construction of ecological civilization is a millennium plan for the sustainable development of the Chinese nation, and pointed out that ecological protection and restoration are major projects in the construction of ecological civilization. Human and nature are the community of life, and human beings should respect nature, conform to nature and protect nature, so as to realize the harmonious development between human and nature [1]. Only by following the laws of nature can human beings effectively prevent detours in exploitation and utilization of nature, and the harm of human beings to nature will eventually hurt themselves, which is an irresistible law. Water is an important resource for human survival, and water resources are one of the important resources to protect and control the ecological environment. It has many kinds of carriers, including rivers, lakes and other different forms [2]. The river and lake water system is not only the channel of flood and the carrier of water resources, but also the core component of national ecological security pattern [3].
2. River ecological environment problem
At present, the problems of river ecological environment mainly include five categories. First, the problem of water quality and sediment pollution, which is manifested in the long-term occurrence of single or multiple indexes exceeding the standard of water quality, and even the phenomenon of black and odorous water bodies, sediment pollution and the continuous release of pollutants into water bodies; second, the problem of insufficient environmental flow, which is manifested in the high ratio of river pollution to diameter, and the lack of basic flow or even drying up; third, the problem of unnatural shape of the river channel affected by high artificial disturbance. It is manifested as the loss of longitudinal connectivity caused by artificial straightening and channeling of river channels, and the loss of biological habitat caused by the construction of high-density sluice DAMS and basements; fourth, the problem of serious decline in biodiversity. It is manifested as incomplete food chain in the channel, extremely low ecological diversity and integrity of higher aquatic plants, fish, macrobenthos and plankton, and the biological invasive species such as alternanthera philoxeroides; fifth, the problem of loss of function in riparian buffer zones. It is manifested that the construction of riverbank buffer zone only pays attention to landscape function and economic function, but neglects ecological function (material, energy exchange function, amphibious and terrestrial biological migration channel function) and protective function (absorption, filtration, purification into river non-point source pollution).

3. Analysis on the causes of ecological degradation of river water
River ecosystem refers to the ecosystem formed by the combination of the biological community living in the river and its surrounding environment, which includes biological and abiotic environment. River ecosystem degradation refers to the process of disharmony between organisms and environment in river ecosystem under natural or man-made disturbance, resulting in damage to system integrity, structural damage, functional decline and even loss. It is the premise and key point of river ecological restoration and management to find out the causes affecting river ecosystem degradation.

Human activities are the main stress factors causing river ecosystem degradation. Aiming at the ecological environment problems of five kinds of rivers, the causes of river water quality, water quantity, channel shape (habitat), riparian zone and biological community degradation are analyzed respectively.

First, the discharge of domestic sewage, industrial sewage and initial rainwater, as well as non-point source pollution of farmland, are the main reasons for the deterioration of water quality, eutrophication of water bodies and even the phenomenon of black and odorous water [4-7]. Second, the over-exploitation and utilization of water resources is the main cause of the serious shortage of environmental flow. Third, the implementation of large-scale river channel reconstruction projects such as channelization, rigidity and straightening are the main causes of the unnatural form of rivers. Fourth, the transformation and encroachment of riverbanks by human beings are the main causes of the loss of function of riverbanks. Fifth, under the combined effect of the above causes of degradation, the degradation of river water quality, water quantity, habitat and riparian zone will result in a short period of time response of the river biome structure and the number of organisms.

4. Principles, measures and methods of river ecological restoration

4.1. Principles of river ecological restoration
The river ecological restoration should design the corresponding restoration target according to the different social demand and ecological function demand of each ecosystem landform condition, hydrological water quality condition, biological condition, river function condition, and combine the degradation condition and restoration demand. The main restoration principles include adjusting measures to differing conditions, economic viability, multi-objective consideration, habitat and biological restoration and overall landscape.
Ecological restoration measures are divided into management measures and engineering technical measures. The management measures can effectively control the pollution from land sources into rivers and strengthen the protection of river ecological environment; the engineering technical measures are mainly to repair and restore the degraded river ecosystem. Plus, the management measures can realize the effective control of the pollution of the land source into the river and strengthen the protection of the river ecological environment; the engineering technical measures are mainly to repair and restore the degraded river ecosystem.

4.2. Measures for river ecological restoration and management

In order to strengthen the pollution control and ecological environment protection, the river ecological restoration management measures mainly include the following six aspects. First, it should vigorously implement the mode of thorough diversion of urban rain sewage. The main cause of river pollution is the confluence or incomplete separation of rainwater in urban drainage system. Based on relevant experience at home and abroad [8-12], the rainwater drainage network must be completely separated, the sewage pipe network should be discharged directly into the sewage treatment plant, and the rainwater pipe network should form a separate drainage system to eliminate any connection. The sedimentation basin should be set up before entering the river, and the water body of the river and lake shall be put into the water body after the precipitation and filtration of rainwater, so as to avoid the direct discharge of rainwater into the water body of the river and lake, and to eliminate the pollution of the water body of the river and lake caused by the initial rainwater to the greatest extent.

Second, it should strictly enforce administrative law and resolutely put an end to the indiscriminate dumping of garbage and sewage into rivers and lakes. Water administrative departments at all levels should conscientiously implement relevant laws and regulations, conscientiously enforce laws and regulations, strictly enforce the law, investigate violations of the law, and do a good job in river and lake management and law enforcement in all directions, throughout the river basin and meticulously, and resolutely curb all kinds of illegal pollution.

Third, it should strengthen the collection and management of garbage and waste and its recycling mode, and develop the recycling economy. It should promote classified recycling, classified treatment, classified recycling or harmless treatment of garbage, and put an end to disorderly dumping, filling and burying of garbage, so as to realize a circular economy with sustainable development.

Fourth, it should popularize the formula fertilization techniques for soil testing in agriculture, apply fertilizer and pesticides with precision, implement advanced technologies such as low toxicity and low residue application, biological control of diseases and insect pests, gradually reduce the use of chemical fertilizers and pesticides, vigorously develop green ecological agriculture, and effectively control agricultural non-point source pollution [13-14].

Fifth, it should strengthen the monitoring and assessment of river section water quality. Environmental protection departments and water conservancy (water affairs) departments at all levels should strengthen the monitoring and management of river water quality, set up water quality monitoring stations scientifically, carry out full-time and dynamic monitoring of river water quality in time and space, formulate measures for water quality assessment and management, set up reward and punishment measures and punish administrative areas where rivers do not meet the standards in accordance with relevant regulations.

Sixth, it should regulate river reasonably, ensure the ecological base flow of rivers and enhance river connectivity. Over-exploitation and monopoly control of surface water resources should be curbed. The water administrative department should exercise its jurisdiction to formulate water resources dispatching plans, water distribution plans and water system dam management and dispatching plans in accordance with the river basin distribution map, so as to ensure the basic ecological base flow of rivers and maintain the water system self-purification capacity, and at the same time strengthen the planning and construction of water system connection projects, so as to realize the goal of incorruptibility of running water and continuous improvement and enhancement of river water quality.
4.3. Technical measures for river ecological restoration engineering

The engineering technical measures of river ecological restoration mainly include river water quantity control technology, river pollution control technology, river habitat restoration technology and biodiversity restoration technology [15-20].

First, the river water quantity control technology. Water quantity control technology mainly includes sluice dam flow control, river water supply technology and diversion ecological restoration technology. The specific technical characteristics and scope of application are shown in Table 1.

**Table 1. Technical characteristics and application scope of river water quantity control**

| Restoration technology       | Technical characteristics                                                                                      | Scope of application                                                                 |
|------------------------------|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Control of sluice dam flow   | This technology is mainly aimed at the lack of ecological base flow due to the excessive sluice dam, which can increase the ecological base flow in the river channel through the regulation of the excess water quantity and time of the sluice dam, thus improving the ecological damage problem caused by the control of the sluice dam. | It is mainly used in rivers which lack ecological base flow due to excessive sluice dams. |
| River water supply           | This technology is mainly used to supplement the water body which is lack of ecological basic flow by water transfer in or out of the basin. This technology can not only replenish water in river channels, but also replace the river water in the dead area by scouring and diluting the polluted water area, so as to change the river from anaerobic state to aerobic state. It can also reduce the pollution load of the water body in a short period of time, improve the living environment of aquatic animals and aquatic plants, promote the self-purification ability of the river and improve the quality of the water environment. | It is suitable for water deficient rivers or as a supplementary measure to improve river water quality. |
| Diversion ecological restoration | It is mainly to break the confluence effect of the base flow. In the dry season with small amount of water, the river can be intercepted by establishing an ecological plug system to form braided flow and increase the contact surface between the river and the river vegetation, so as to ensure the normal operation of some regional ecological systems. | It is mainly applicable to the restoration of rivers with lack of ecological flow and often broken flow. |

Second, the river pollution control technology. River pollution control technology mainly includes chemical remediation technology, sediment dredging technology, microbial remediation technology, channel oxygen enhancement technology, ecological floating island technology, artificial wetland technology and oxidation pond technology. The specific technical characteristics and scope of application are shown in Table 2.

**Table 2. Technical characteristics and application scope of river water quality remediation**

| Restoration technology       | Technical characteristics                                                                                      | Scope of application                                                                 |
|------------------------------|---------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------|
| Chemical purification technology | The technology is a chemical treatment of polluted water to remove pollutants in water. The chemical purification method is quick in effect, high in repair efficiency and easy to operate. However, since the chemical agent is added, the treatment cost is relatively large, and it is easy to | It is applicable to the restoration of water bodies that require emergency treatment, generally only as an emergency measure. |
| Restoration technology | Technical characteristics | Scope of application |
|------------------------|---------------------------|----------------------|
| Sediment dredging technology | This technology refers to the removal of pollutants in contaminated sediment or sediment by physical methods (mechanical dredging or hydraulic washing), so as to reduce the release of sediment pollutants upward overlying water body and alleviate endogenous pollution, which is the most widely used treatment technology at present. The technology has a quick effect on pollution treatment, but it is difficult to control the dredging depth accurately due to the large amount of engineering, high investment and easy to cause sediment re-suspension pollution of water. | It is mainly suitable for the restoration of some seriously polluted river sections with sediment. |
| Microbial remediation technology | The technology is to use microbial agents to change the redox state of pollutants, and then reduce or eliminate the concentration of pollutants. Compared with other remediation techniques, microbial remediation has many advantages, such as fast propagation, variety, short growth period, good purification effect, easy management and low cost. | It is suitable for quick repair of seriously polluted rivers. |
| Channel oxygen enhancement technology | The technology can also be called artificial oxygenation technology, mainly refers to the improvement of the river base, the setting of stone cage dam, the dropping of riprap, the construction of river habitat islands and the construction of deep pool-flash, so as to increase the hydraulic cycle, accelerate the rate of redox reaction between dissolved oxygen and pollutants, and increase the activity of aerobic microorganisms to achieve the purpose of degrading organic pollutants. | It is mainly suitable for remediation of polluted water with static or slow flow in front of dam. |
| Ecological floating island | The technology is a floating island with aquatic or terrestrial plants and habitats for wildlife. Using floating islands as carriers, plants are planted on the water surface to absorb pollutants and reduce the content of chemical oxygen demand, total nitrogen, total phosphorus and heavy metals. At the same time, the plant roots on the floating island have a huge surface area, which provides a good solid carrier for microbial growth in water. The technology has a small amount of engineering and can realize the sustainable utilization of resources. | It is suitable for small rivers with no shipping requirements. It is generally selected in the wider part of the river, or in the artificial excavated estuary set floating island, also can be designed small floating island, sporadic multi-point distribution. |
| Artificial wetland technology | This technique mainly uses the triple synergy of physical, chemical and biological in natural ecosystems to remove pollutants from water bodies. The artificial wetland is built around the river or on the flood plain. Sewage is introduced into the constructed wetland through terrain or | It is suitable for the heterotopic treatment of river water quality in vast rural areas with abundant land, low level of economic development, shortage of energy and relative lack of technical force. |
Restoration technology and the sewage is treated back into the river. In the case of rainstorm, storm runoff can be introduced into the constructed wetland for treatment, so as to reduce non-point source pollution.

**Stabilization pond technology**

The technology is a basin system with reservoirs as the point and ditches as the line, using natural low-lying land to dam or manually excavate reservoirs to reduce non-point source pollution.

Third, river habitat restoration technology. In view of the problem of reducing the biodiversity of rivers, the technology of habitat restoration, ecological revetment, biological grid, river beach and riparian zone restoration, and ecological island can be adopted. The specific technical characteristics and scope of application are shown in Table 3.

**Table 3. Technical characteristics and application scope of river habitat improvement**

| Restoration technology | Technical characteristics | Scope of application |
|------------------------|---------------------------|----------------------|
| **Habitat restoration technology** | The technology is mainly used to restore the living places of fish and benthic animals, such as spawning grounds, feeding grounds, stopping grounds and channels. Sites simulating aquatic animal preferences are often constructed by constructing fishways, deep trap-shoals, matrix restoration, riparian mulch, and setting up mounds and groins. | It is suitable for water restoration with a single habitat type. |
| **Biological grid** | The technology uses fallen plant stems to bind together, slows the flow of water and provides a home for aquatic plants, fish and benthic animals. | It is suitable for water body restoration of habitat destruction. |
| **Restoration technology of flood land and riparian zone** | This technique mainly considers that the tidal flat and riparian zone will be submerged periodically, and it is often an important place for the predatory fish in the tidal flat to take bait and lay eggs in the fertile period, so the vegetation in the tidal flat and riparian zone can be restored effectively to the habitat of aquatic organisms. | It is suitable for water restoration with single vegetation type and some non-point source pollution. |
| **Ecological island** | This technology mainly simulates the river-heart continent of natural river channel, enriches the habitat diversity of river channel, creates a variety of flow patterns, provides a diversified habitat for fish and enriches the habitat diversity of fish. | It is suitable for water restoration with single habitat type and single velocity type. |
| **Ecological bank protection** | This technology mainly uses block stone, sand free concrete tank and aquatic plant to carry on the bank protection technology synthetically. Planting aquatic plants at constant water level with blocks of stone at the foot of the slope can take good account of erosion prevention and plant growth. It is also possible to use sand-free concrete member retaining trough at the foot of the slope to plant aquatic plants in the trough and fill pebbles to construct diverse biological habitats. | It is suitable for water restoration in riparian zone with single habitat type, low biodiversity and some non-point source pollution. |

Fourth, biodiversity restoration technology. Biodiversity restoration technology mainly includes vegetation restoration technology, aquatic biological food chain construction technology, aquatic
biological functional group construction technology, fish restoration technology and so on. The specific technical characteristics and scope of application are shown in Table 4.

Table 4. Characteristics and scope of application of river biodiversity restoration technology

| Restoration technology                                      | Technical characteristics                                                                                                                                                                                                 | Scope of application                                                                                      |
|------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------|
| Vegetation restoration technology for river banks           | This technology is to use ecological principles to create a variety of habitat types and different types of ecosystems through the restoration of plant communities composed of grass, forest and other wetland plants in river plains. | It is suitable for various types of river ecosystem restoration.                                         |
| Construction of aquatic biological food chain              | The technology refers to the use of ecological floating islands or biological fences to create a good habitat for aquatic organisms and microorganisms, provide a place of life, and restore the food chain. | It is suitable for water restoration with low biodiversity.                                             |
| Construction technology of functional groups of aquatic organisms | The functional group construction of submerged plants is to plant submerged plants in ecological cages in advance and sink them to the bottom of the river so that plants can grow better in the sediment of the river; the functional group construction of emergent water plants mainly selects local species and uses native organisms to make them grow better in barren rivers and coastal areas; the construction of fish functional group is to attract fish to live and reproduce in this area by means of establishing artificial islands and artificial reefs in river channels; the construction of the functional group of benthic fauna is mainly to release some local species with strong adaptability, and to use a water fence composed mainly of bamboo pieces for culture to form the bottom mud microhabitat. | It is suitable for the restoration of water bodies with low biodiversity and some damage to habitats.     |
| Fish restoration technology                                | The technology mainly includes the addition of fish facilities, set up artificial fishing firewood and fish stocking and other three categories. Over-fishing facilities are engineering measures to connect the migration or migration of fish and are mainly used to increase the migration and migration of fish; the establishment of artificial reefs increases the habitat of fish and benthic organisms and increases the fishing bait and living space of fish; and the stocking of fish can not only complete the food chain, but also play a role in controlling algae, water bloom and purifying water quality. | It is suitable for the restoration of water bodies with low fish diversity, incomplete biodiversity and a certain degree of habitat destruction. |

5. Application case of river ecological restoration project
River ecosystem is a large and complex natural system that contains physical and chemical systems such as water, biology and plants [21], and it determines the complexity, systematicness and long-term nature of its restoration work. River ecological restoration mainly includes the following six steps: first, problem assessment and diagnosis evaluation of river ecological status; second, special planning for river restoration and formulation of work objectives and contents; third, determination of the scope of river management and restoration; fourth, the comprehensive evaluation of ecological degradation. It starts from the source, carries out supervision and management of water ecological protection and puts an end to the discharge of pollutants into water areas; fifth, implementation of comprehensive...
management measures, engineering measures and non-engineering measures as a whole step by step; sixth, according to the monitoring and evaluation of measures, professional management and public participation will be combined to form a benign atmosphere. At present, the typical river ecological restoration engineering cases in China are shown in Table 5.

| Table 5. Cases of domestic river ecological restoration projects |
|-----------------------------------|---------------------------------|---------------------------------|---------------------------------|
| Name of river and lake           | Regulation length/volume        | Key technologies               | Water quality before treatment                           | Water quality after treatment                           | References |
| Wuxi Ancient Canal               | 1.5 km 75,000m³                | Water diversion, aeration, biological carriers, aquatic plants | COD$_{cr}$=139 mg/L NH$_3$-N=8.22 mg/L TP=0.53 mg/L | COD$_{cr}$=35 mg/L NH$_3$-N=1.7 mg/L TP=0.22 mg/L | [17]        |
| Beijing Tongzi River             | 3.5 km 216,000m³               | Aeration, water circulation, biological carrier, biological regulation | COD$_{cr}$=63 mg/L NH$_3$-N=0.58 mg/L TP=0.48 mg/L | COD$_{cr}$=28 mg/L NH$_3$-N=0.2 mg/L TP=0.19 mg/L | [17]        |
| Micro-contaminated River         | /                              | Composite vertical-flow constructed wetland | TN=2.24 mg/L TP=0.193 mg/L | TN=1.19 mg/L TP=0.073 mg/L | [19]        |
| Xi’an Zao River                  | 8000m²                         | Mixed constructed wetland system | COD=350.9 mg/L SS=334.2 mg/L TN=38.5 mg/L NH$_3$-N=27.2 mg/L TP=3.9 mg/L | COD=89.5 mg/L SS=26.7 mg/L TN=16.8mg/L NH$_3$-N=11.6 mg/L TP=1.2 mg/L | [20]        |
| Chang Ge Qingyi River            | 15km                           | Construction of sluice dam dispatching, ecological floating island, ecological revetment and biological function group | COD$_{cr}$=65 mg/L NH$_3$-N=5.02 mg/L TP=1.25 mg/L | COD$_{cr}$=30 mg/L NH$_3$-N=1.8 mg/L TP=0.25 mg/L |          |

6. Prospect of river ecological restoration objectives
The determination of ecological restoration target of river system is essentially to define a desired future river condition [22]. Good water ecological objectives should have the following characteristics: first, rivers with integrity functions; second, biodiversity; third, structural integrity of water ecosystems; fourth, fewer exotic species to protect the living environment; fifth, good water quality (water quality standards, as shown in Table 6) to reduce pollution sources; sixth, beautiful landscape and environment to increase people's well-being.
Table 6. Water quality rehabilitation indicators for a river course [23]

| Indicators            | Standards  |
|-----------------------|------------|
| Dissolved oxygen (mg/L) | ≥3         |
| Permanganate index (mg/L) | ≥10       |
| BOD5 (mg/L)          | ≥10        |
| NH3-N (mg/L)         | More than 15% |
| TP (mg/L)            | More than 15% |
| Water transparency   | More than 15% |

7. Summary
River ecological restoration is a major historical issue, and there is still a long way to go to protect and restore water ecology. In order to realize the goal of river ecological restoration, the party committees and governments at all levels and the water administrative departments should attach great importance to it. The broad participation and support of the whole society should be needed, and the long-term and unremitting efforts of the vast number of water workers, environmental protection workers and ecological builders are also required in order to achieve the desired results. In the future, it will take more than ten years or even decades of continuous work to completely restore the river's ecosystem and the original ecological function of the river, reproduce the healthy vitality of the river, and truly return people a beautiful scenery water ecological environment and make greater contributions to the construction of a beautiful China and the promotion of social progress and human development.

References
[1] Zhang Q. (2018) Ecological Protection and Restoration Countermeasures of River and Lake System [J]. Environment and Development, 30(10): 198, 200.
[2] Li X. (2015) Design Analysis of Comprehensive Management Engineering of a Small Watershed Water Planning and Design, 12: 206.
[3] Huang J.H., Zhao R., Shi X.X., Liao W.G., Zhu D.S. (2018) Ecological Protection and Restoration Countermeasures of River and Lake System [J]. Water Planning and Design, 04: 1-4, 107.
[4] Wu N.N., He Y, Tan Youchen. (2019) Pollution Status and Control Technology of Black-smelly Water in China [J]. Construction and Budget, 11: 79-81.
[5] Liu G. R. (2017) Research on the progress of urban black and smelly water treatment[J]. Jiangxi Building Materials, 18: 128-129.
[6] Xu H., PAERL H. W., Zhu G. W., et al. (2017) Long-term Nutrient Trends and Harmful Cyanobacterial Bloom Potential in Hypertrophic Lake Taihu, China [J]. Hydrobiologia, 787(1): 229-242.
[7] Qin B. Q., PAERL H. W., BROOKES J. D., et al. (2019) Why lake Taihu continues to be plagued with cyanobacterial blooms through 10 years (2007-2017) [J]. Science Bulletin, 64(6): 354-356.
[8] Wang J.J. (2019) A Study on Diversion Reconstruction of Municipal Rain Sewerage Pipes Engineering Construction and Design, 22: 80-82.
[9] Tu M. (2019) Construction Technology of Municipal Rain Water Diversion Pipe Network J]. Henan Science & Technology, 31: 102-103.
[10] Luo G.D. (2019) A Study on Rural Rain Pollution Diversion System [J]. Chemical Management, 23: 50-51.
[11] Yang Z.L. (2017) Discussion on Diversion Reconstruction of Municipal Rain Sewerage Pipeline [J]. Shanxi Architecture, 12: 106-108.
[12] Range, Wolfgang. (2019) Principles for constructions of pipelines for water management and diversion of water from torrential rains in urban areas [J]. WASSERWIRTSCHAFT, 109(1): 41-49.
[13] Song D.P., Chen W., Gao Y.Z. (2011) Rationality and Environmental Effects of Huaihe River for
Nitrogenous Fertilizer Application [J]. Journal of Agricultural Environmental Sciences, 30(6): 1144-1151.

[14] B. N. Ryzhenko. (2011) Technology for predicting groundwater quality: Application of physicochemical numerical simulations in evaluating groundwater pollution hazards. Preparing water supply intakes[J]. Geochemistry International, 49(2): 196-198.

[15] Liu Q.Q., Li H.Z., Li X.J. (2019) Advances in Biological-Ecological Restoration Techniques in River Regulation [J]. Guangdong Chemical Industry, 24: 61-63.

[16] Xu D.Y. (2018) Application of Water Ecological Restoration Technology in River Regulation [J]. Resource Conservation and Environmental Protection, 12: 56.

[17] Lu C.X., Huang Z.F., Wang S.J. (2014) Comprehensive remediation techniques and applications of urban polluted rivers and lakes [J]. Environmental Science and Management, 39(05): 111-114.

[18] Wu Z.B., Qiu D.R., et al. (2001) Effects of aquatic plants on water purification of nutrient-rich water [J]. Wuhan Plant Research, 19(4): 299-303.

[19] Xu P., Xiao E., He F., et al. (2019) High performance of integrated vertical-flow constructed wetland for polishing low C/N ratio river based on a pilot-scale study in Hangzhou, China[J]. Environmental Science and Pollution Research International, 26(22): 22431-22449.

[20] Zheng Y., Wang X.C., Dzakpasu M., et al. (2016) Performance of a pilot demonstration-scale hybrid constructed wetland system for on-site treatment of polluted urban river water in Northwestern China[J]. Environmental Science and Pollution Research International, 23(1): 447-454.

[21] Zhang H.Y., Tang Y.Z., Gu J.Y. (2016) A review on the research progress of water purification effect in water ecosystem [J]. Environmental Science and Technology, 39(1): 79-86, 198.

[22] Dong Z.R., et al. (2013) Ecological restoration of rivers [M]. China Water Conservancy and Hydropower Press, Beijing.

[23] Zhao X.H. (2019) A Preliminary Study on the Protection and Ecological Restoration Measures of River and Lake Water System in Sponge City Construction [J]. Science and Technology Innovation Bulletin, 16(30): 93-94.