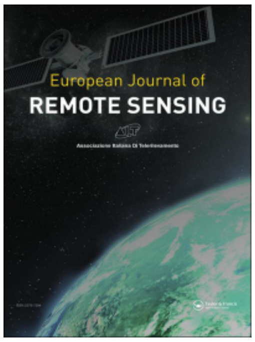

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The research on landscape restoration design of watercourse in mountainous city based on comprehensive management of water environment

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ABSTRACT
Urban river course is one of the important influencing factors of urban landscape. Under the effect of peripheral land use, municipal facilities, historic and cultural environment, etc., it needs to consider its own function, configuration and the relationship with the city, balance its benefits in water management, flood-control and landscape ecology. This study concluded existing problems of river course in the mountainous city with the comprehensive water environment treatment project of Xiaojia River and Tiaodeng River area in Chongqing as an example, developed systematic methods and approaches of the work, summarized the design process integration of landscape and water environment management, with a view to provide theoretical guidance and reference for the same type of urban river landscape restoration.

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KEYWORDS
Urban river course; water management; ecological restoration; landscape design

Introduction

Rivers are important water resources in the urban environment, yet they are said to limit the survival and development of cities too; the ecological problems of urban rivers escalate with increasingly accelerated urbanization. The contentions between urban development and water requirement affect the questions related to the urban water space and the capacity of rainwater storage, which also cause the river channels to become less natural and damage the biodiversity. Some urban river channels gradually develop into sewers with seriously polluted water, urgently requiring ecological restoration. (Zhang, 2012) After the 18th National Congress of the Communist Party of China (NCCPC), the nation has been promoting the construction of an ecological civilization, and the concept of environmental protection and green development is deeply rooted. The polluted rivers are being rebuilt and the pollution controlled so as to protect and restore the water resources and the mountains. Since the situations of the most river channels in the urban areas are complicated, a large part of the common ecological restoration work on urban rivers is guided by the ecological environment problems and promoted by the special restoration project of pollution control, with a single goal. Further, no systematic restoration work comes under the plight of the stop-gap measures, and few of them are designed and implemented from the planning level practice guidance. As of now, there is no replicating restoration mode and technical process for how to integrate water environment management and landscape construction on both sides of the river to completely repair the urban river course, consolidate the results of governance and improve the urban landscape.

In this study, based on the comprehensive water environment improvement project of the Tiaodun and Xiaojia rivers in Chon gqing, we explored the design and technique of landscape ecological restoration of polluted river channels in mountain cities to provide macroscopic guidance for similar problems for other urban river course.

Related concepts of urban river landscape ecological restoration

Urban river channels mainly refer to existing rivers in the urban built area, which are linear rivers that flow through or originate within the city. An urban river channel is usually a river section with a small area and base flow, formed naturally or by artificial excavation. Urban river channels have a certain influence on the local ecological pattern and climate change, with the functions of reducing pollution and regulating climate conditions as well as landscape services. As the urban river channels are usually located in high-density areas, the ecological imbalance caused to them by human activities is quite serious.[1]

The urban watercourse landscape includes the visual environment design of the watercourse and surrounding urban areas as well as adjacent areas. It contains three main parts of the landscape: the main

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[1]EPC+O: Engineer, Procure, Construct and operation.

water area, the slope protection (the land area), and the coastline (the land-water area), which also includes landscape structures close to the river, the architecture, the landscape sketch, and the vegetation.

Ecological restoration of the urban river course promotes the restoration of the river ecosystem to a more natural state through appropriate artificial interventions. These are physical, biological and ecological processes of clearing and repairing damaged river courses, making it more healthy, stable, sustainable and improving the value and maintaining the biodiversity of the ecosystem.

For the landscape ecological restoration of the rivers flowing through a city, the main task is to carefully investigate and evaluate the state of the rivers, then design the plan, and eventually repair the ecological system.

Current research and implementation in China

Studies on river ecological restoration began in China in the 1990 s. At present, the theoretical framework, restoration strategy, methods, and techniques have been explored from multiple aspects, and some achievements have been made. The restoration contents of river landscape ecology mainly focus on the specific methods of riverbank line shape, riverbank and slope structure, river buffer zone landscape plant configuration, etc. The restoration contents of river water body mainly focus on water environment treatment, water conservancy project safety, water quality restoration, species diversity maintenance, river ecosystem balance, and other water ecological restoration technological operation method.

Quantitative analyses of river channel spaces based on ecological theory have espoused landscape planning and ecological regulation strategies for different channels and spatial patterns (Fu & Dong, 2012). Design methods for river spatial patterns, ecological slope protection, wetland protection and restoration, water resources protection and utilization, non-commercial forests, and biodiversity conservation have been explored (Wang & Sun, 2014). Research has also been focused on the ecological restoration technology of water environment based on the principles of landscape co-construction, such as hydrodynamics control, river sediment quality improvement, river space restoration, and water quality enhancement (Liu, 2015). The restoration of river landscape ecology mainly concentrates on specific methods related to river morphology, structures of riverbank and slope, and landscape plant configuration in riparian buffer zones. Additionally, the remediation of water bodies primarily focuses on water environment treatment, safe hydraulic engineering construction, water quality restoration, species diversity maintenance, river ecosystem balance, and other technical methods of water ecological restoration. For example, some studies explored the disadvantages of traditional hydraulic engineering and its adverse effects on the river ecosystem, and it was suggested that the survival needs of the wild animals and plants should be fully considered in the design of water conservancy engineering to ensure the health of the river ecosystem; a series of restoration engineering techniques were suggested, accordingly (Dong, 2003). Besides, some other studies have been focused on the biocompatible construction of environmental patches, ecological restoration materials, and the self-organizing mechanisms in the process of coastal ecosystem restoration (Yang et al., 2004). In short, integrated landscape and river ecological restoration by ecological and water conservancy engineering seem to be the areas of importance in river channel management.

However, most studies tend to focus on a segregated model with separate environment improvement tasks and landscape restoration models; a case of comprehensive ecological restoration and landscape repair is found seldom. A comprehensive system engineering approach for ecological restoration in urban river landscape should be able to work with various situations, terrain conditions, complex historical causes, and urban construction, and not just in closed, simulated, and perfect environments. As the ideal, theoretical model cannot reach the perfect effect in real, complex environments, it cannot function as a guiding model. The ideal model needs full consideration of various factors such as urban planning, land ownership in the past and at present, investigation into the rivers, engineering treatment, ecosystem restoration, landscaping improvement, water security, and river control to meet the water quality purification standards, have a stable ecological base flow, and repair the landscape ecology on both the banks of the rivers. Furthermore, this could make the urban river surroundings more liveable and increase the land values and achieve a win-win situation realizing ecological, social, and economic benefits.

In the past, river management and landscape restoration were usually carried out under different institutions and different professional systems. Municipal departments were responsible for pollution control; environmental protection departments were responsible for ecological restoration and ecological evaluation indicators; landscape design departments were responsible for landscape design, only focusing on the tasks within their own management scope. There was no proper connection and cooperation.

At present, there are no perfect operation models and technical processes explaining how to proceed with the landscape ecological restoration of urban rivers under complicated and changeable environments, resolve the multi-faceted problems, set effective assessment measures, and complete the project successfully. (Lin et al., 2018) Taking the two rivers' basins in Chongqing as an example, this study has suggested a systematic working method and path from the background investigation, planning and deployment of the basin to the overall scheme, technical route and implementation mechanism, and summarized the integrated process of river landscape design and water environment management.

Methods in landscape ecological restoration of river channels in the mountain city

In this study, based on the project of comprehensive water environment improvement of the Tiaodun and Xiaojia rivers in Chongqing, we combined the action concept of green development with ecological priority with a sustainable planning method and implementation approach to form a coherent design logic, repair model, and technical process having certain demonstration values and a reference point.

Sites and compilation foundations

The Tiaodun and Xiaojia rivers, with a total land area of 35.8 km^2 and a length of 27.9 km, are located in the Liangjiang new district, Chongqing. The Tiaodun river stretches 11.7 km, and the total length of mainstream and tributaries together is 11.8 km and it is 16.0 km (within the area of the Liangjiang new district) and 9.4 km, respectively, for the Xiaojia river, and 8.1 km (within the area of the Liangjiang new district) and 6.7 km, respectively, for the Maoxi river. The land on both sides of the river is used mainly for residential purposes, followed by commercial usage, and green areas. It is difficult to perform comprehensive water environment management in the area due to the complex nature of usage and the existing situation of the rivers (Figure 1).

Chongqing Urban–Rural Master Planning (2007–-2020) (2014 edition) put forward the request for Chongqing to build itself into a beautiful mountain-water city, highlighting the beauty of ecology and culture. At the same time, according to Chongqing Action Plan for Implementing Ecological Priority and Green Development (2018–2020), overwhelming priority should be given to restore the ecological environment of Yangtze and build an important ecological barrier in the upper reaches of the river. Therefore, the current project adopted the operation model of EPC+O[1] based on the ecological restoration concept of comprehensive water environment treatment and integrated designing, procurement, construction, and operation maintenance to it. Through the comprehensive treatment of the two rivers, the water quality meets the national IV standards and the ecological base flow is stable so that the river flow does not stop. Besides, the repair of the landscape ecology on the riverbanks should make the environment liveable and increase the land values, thus making it a comprehensive water environment management model in the Liangjiang new district of Chongqing.

Effective work routes

Our survey of this project showed that the river channel longitudinal slope was steep, as in typical mountain-watershed topography. The total length of the culvert was 9.68 km, accounting for 35%. Several lakes and six reservoirs existed in the basin with a total storage

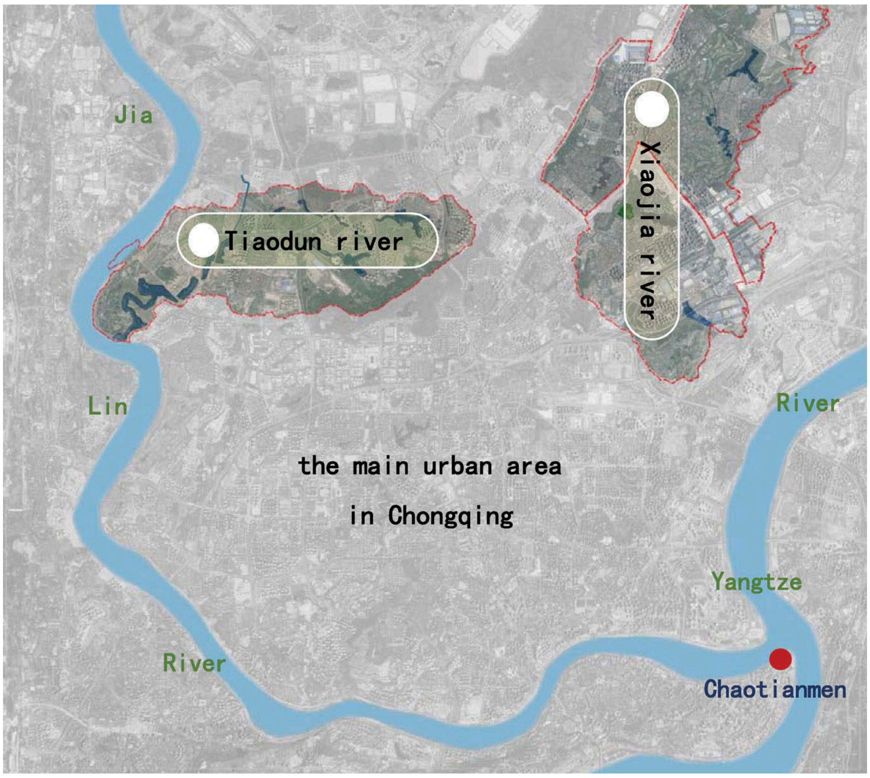

Figure 1. Locations of the Tiaodun and Xiaojia rivers.

capacity of 3,214,700 m^3. There were two river basins with a total storage capacity of 784,600 m^3 for the Tiaodun river and four with a storage capacity of 2,430,100 m^3 for the Xiaojia river. The main drainage system is rain and sewage and it is still incomplete. The Tiaodun river, located in the section within the service range of Jiuqu river wastewater treatment plant, according to the design, had excess capacity and planned diversion system but there occurs a huge mixing of rainwater and sewage. Although there were trunk sewers built along the river, the problems of local disconnection and some beheaded emission existed. The Xiaojia river and the Maoxi river, located in the service areas of Xiaojia and Tangjiatuo sewage plants, respectively, had excess capacity and planned diversion systems as per the design but the mixing of rainwater and sewage is very high.

In the comprehensive improvement of river water environment, background investigation is the basis of all the work, and the key step is to find out the current situation of river basin and the pollution source. Therefore, firstly, an investigation was made into the current situation of both the rivers and the environmental data were collected. Secondly, the four design systems of clear water, green land, water safety, and automatic management were put forward to guide the whole work, including the eight projects of sewage collection system, rainfall-runoff pollution control, endogenous pollution control, ecological restoration, ecological base flow security, water safety, promotion of landscape greening, and river control. The specific routes and content are as follows (Figure 2).

Investigations and the work environment

Investigations on the river

The investigations covered point-source pollution, non-point source pollution, endogenous pollution, and water quality detection. Based on the systematic overall plan for the landscape ecological restoration of the rivers, the water environment investigation was implemented with proper methods for three checks (water source, water quantity, and water quality), two tests (water flow and water quality), and two-way collaboration. Water source, water quantity, and water quality were determined by tracing the pipes with site surveys and discharging point checks. Water flow was monitored and water quality was tested using a box-culvert endoscope and pipe endoscope. The two-way collaboration between the endoscope and the outside continuously monitors the water flow and water quality; this made the results more accurate with paired data from multi-unit and multi-batch tests.

In the investigation of point-source pollution, discharging point checks, sewage checks, and combined discharging point checks were conducted for the Tiaodun and Xiaojia rivers, and it was found that a large amount of pollution load was input to the two rivers from each discharging point; this can be seen in the results of point-source pollution in the Xiaojia river (Table 1). Also, many wrong connections were found between rain and sewage pipes, which needed to be corrected. The structure of the pipes in the rivers was also flawed, and repair was urgently needed (Figure 3).

In the investigation on non-point source pollution, this paper mainly investigates the surface runoff pollution caused by the precipitation process. Based on "Special planning of sponge city in Chongqing", the Tiaodun river is located in the drain partition of Zengjiaxi Sponge city, it was found that there were 48 discharging points for rainwater for the river, and the total annual runoff control rate from Sponge City was 67.2%. The Xiaojia river, located in the drain partition of Shuangxi Sponge city, had 74 discharging points; the total annual runoff control rate from Sponge City was

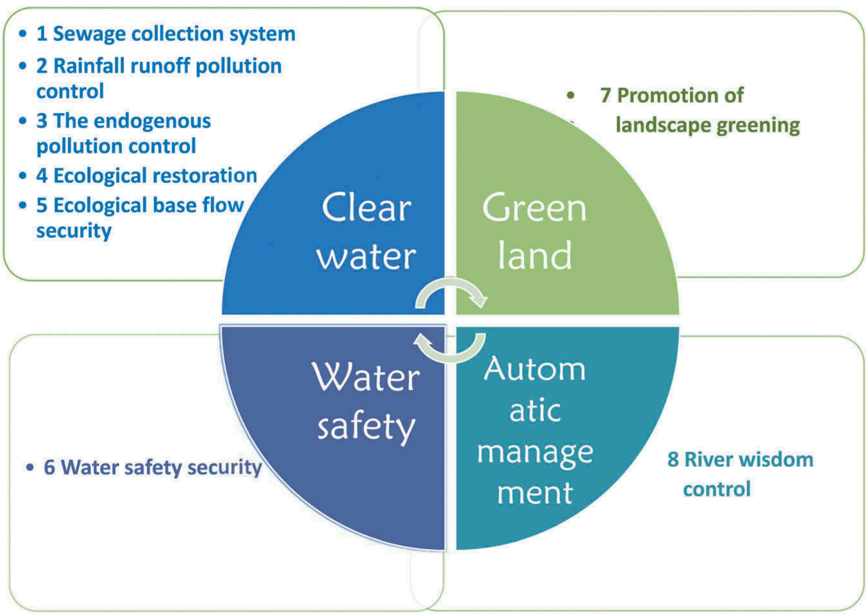

Figure 2. Schematic diagram of the four systems and eight projects.

Table 1. Load statistics of point-source pollution in the Xiaojia river.

			Water Quality(mg/L)			Water Flow	Pollutant load(t/a)		
NO.	Point No.	Location No.	COD	TP	NH3-N	Q(m3/h)	COD	TP	NH3-N
1	X01	PS1417	59.75	0.5	3.1	28	14.66	0.12	0.76
2	X02	PS10478	74.75	0.54	12.04	23.2	15.19	0.11	2.45
3	X03	PS1305	79.75	0.59	11.35	21.1	14.74	0.11	2.1
4	X04	PS8427	88.5	0.58	10.3	49.4	38.3	0.25	4.46
5	X05	PS2174	128.5	0.68	11.22	7.9	8.89	0.05	0.78
6	X06	PS3258	146.75	1.01	17.29	2	2.57	0.02	0.3
……	……	……	……	……	……	……	……	……	……
24	X24	PS1044	43.5	0.39	7.1	2.35	0.9	0.01	0.15
25	X25	PS3271	74.75	0.54	12.04	0.5	0.33	0	0.05
SUM						291.275	212.61	1.55	28.87

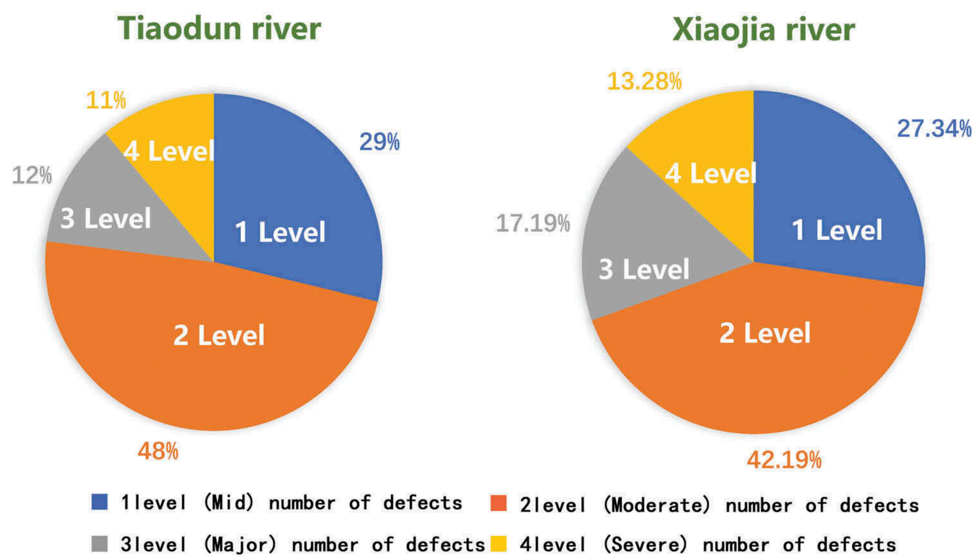

Figure 3. The proportion of pipes with structural defects in the two rivers.

58%. The analysis of the ground surfaces of the two rivers found that the proportions of water surface and green area were small, the hard underlying surface accounts for the majority, the runoff coefficient is large, the time of runoff formation is short, the amount of underground infiltration is small, the erosion of pollutants is strong, and the rainwater runoff pollution in the early stage of a rainstorm is serious. In the Tiaodun river, the percentages of water surface, architecture, roads, other hard pavement and green areas were 2%, 39%, 18%, 18%, and 23%, respectively. The percentages for the Xiaojia river were 2%, 55%, 17%, 20%, and 6%, respectively. In other words, non-point source pollution could not be ignored (Figure 4).

In the investigation on endogenous pollution, the survey of the area, silt depth, and silt volume of each reservoir in the two rivers were made and heavy metal pollution in sediments and organic matter was determined. No heavy metal pollution was found in the sediments, but it was found in the organic matter thus requiring control in the areas of the Xiaojia river, Changtiangou, Gaoshi, and the Duanqiaowan reservoirs. Since, the Caijiagou Majitang reservoir has not been released, there is no need to take control measures.

In the investigation of water quality, 94 monitoring sites were identified in the two rivers. Nine hundred and seventy-five samples were collected from November 2018 to April 2019. The testing data indicated that the water quality of the Tiaodun river was poor, at standard V, with eutrophication and exceeding total phosphorus (TP) levels. While for the Xiaojia river, the water quality was mostly at standard IV and partially at standard V, and the degrees of eutrophication varied. Ammonia, nitrogen, and TP were out of the limits. The pollutant load in the two rivers exceeded the environmental capacity, underlining the need for engineering measures to reduce the pollutants.

Investigation on the water resource

The data from Yubei weather station showed that the mean annual precipitation was 1090.1 mm, and the maximum and minimum annual precipitations were 1441.7 mm and 891 mm, in 2004 and 2010 respectively. The average annual evaporation was 662.8 mm, and the evaporation peaks occurred from July to August, accounting for 35% of the annual amount. Rainfall in the earlier 12 h and 6 h of a day accounted for 98.3% and 92.6% of the total, respectively.

The six reservoirs in the rivers had high water depth and steep coasts, in line with the terrain characteristics of Chongqing. All of them had been changed to

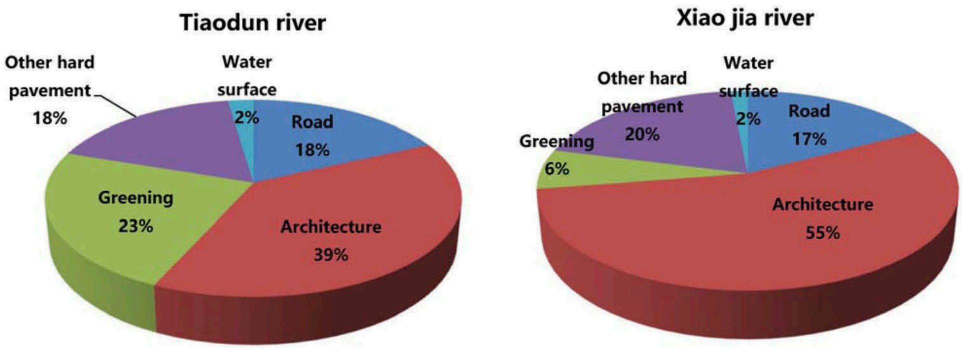

Figure 4. The percentages of ground surface in the drain partitions of the Two rivers.

landscape lakes with overflow flood spillways, thus weakening the functions of regulation and storage.

The Tennant method was used to investigate the ecological base flow of the rivers, with a 20% average annual runoff. The ecological base flow of the Tiaodun river was 4400 m^3/d, and it was 3000 m^3/d and 2600 m^3/d for the eastern tributary of the Xiaojia river and the Maoxi river, respectively. The replenishing water required a standard of IV of surface water. The water replenishment points are all located behind the dam of the reservoir and at the beginning of the river course of the two river basins.

Investigation on water ecology

The classification of aquatic animals and plants in the reservoirs was made and the analysis of the system structure of aquatic animal and plant communities was conducted. In the river channels, the dominant aquatic plants were *Phragmites australis, Oenanthe javanica*, and *Cyperus alternifolius. Phragmites australis, Humulus japonicas, Thalia dealbata Rhapis excels, Nephrolepis cordifolia, Sambucus javanica, Typha orientalis, Rumex acetosa*, and so on were the hygrophytes found. The floating plants included *Pistia stratiotes, Acorus calamus, Nymphaea tetragona, Myriophyllum verticillatum, Zizania latifolia*, and *Spirogyra*. There were *Hypophthalmichthys nobilis* and *Hypophthalmichthys molitrix* in the reservoirs, while no fish existed. Due to the small width and the less water volume of the urban rivers, the ecological base flow was not stable, and the aquatic species diversity was low, also led to short food chains, incomplete community structures and functions of aquatic animals and plants, and weak production capacity and self-purification capacity of the waterbodies.

Shorelines and water safety investigation

The investigations on river shorelines and water safety are done for assessing the difficulty of implementation and management. It was found that the river channels were narrow with steep coasts. The proportion of buried culvert was up to 35%, and the depth of the box culvert was between 8 m and 23 m, which lacked the conditions to be transformed into open channels (Figure 5–6). However, most of the reservoir shoreline was surrounded by residential areas and with high levels of privatization. In addition, some illegal constructions have encroached the reservoir. Therefore, it was understood that more attention should be put on the open reservoir, while the closed reservoir would be improved partially.

In addition, the structures and architectures around the two rivers were also investigated, including the weirs, box culverts, pipes, railway bridge, and the highway bridge. Safety evaluation of the reservoir dams was made from five aspects such as flood control, seepage behavior, structure state, vibration resistance, and the metal structure. Besides, an evaluation of the current flood-carrying capacity was made, and the results showed that it could meet very high standards.

Based on the background surveys mentioned above, the key problems of the two rivers were found to be eutrophication in the reservoirs, the poor water quality of standard V, and the insufficient water ecological base flow. The water quality, quantity and pollution of the river will seriously affect the ecological environment of the two river basins (Table 2).

Solutions and measures

In view of the problems related to the rivers, the ecological restoration plan was systematically performed based on the principles of clear water, green land, water safety, and automatic management, including the eight projects of the sewage collection system, rainfall-runoff pollution control, endogenous pollution control, ecological restoration, ecological base flow security, water safety, promotion of landscape greening, and prudent river control.

Firstly, pollution control started from the source based on the sewage collection system, and then the reduction measures were taken by the rainfall-runoff pollution control with the concept of the sponge construction. Besides, endogenous pollution also needed to be controlled. On the basis of source sewage control, complete food chains and ecosystems had to be built through recovering habitats and biodiversity, to

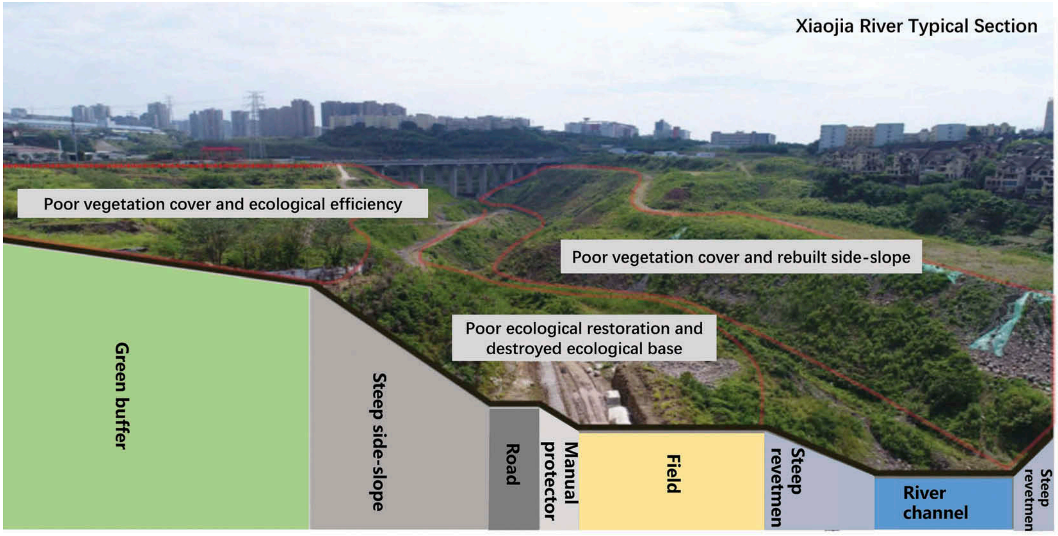

Figure 5. Typical cross-sections of the Xiaojia river.

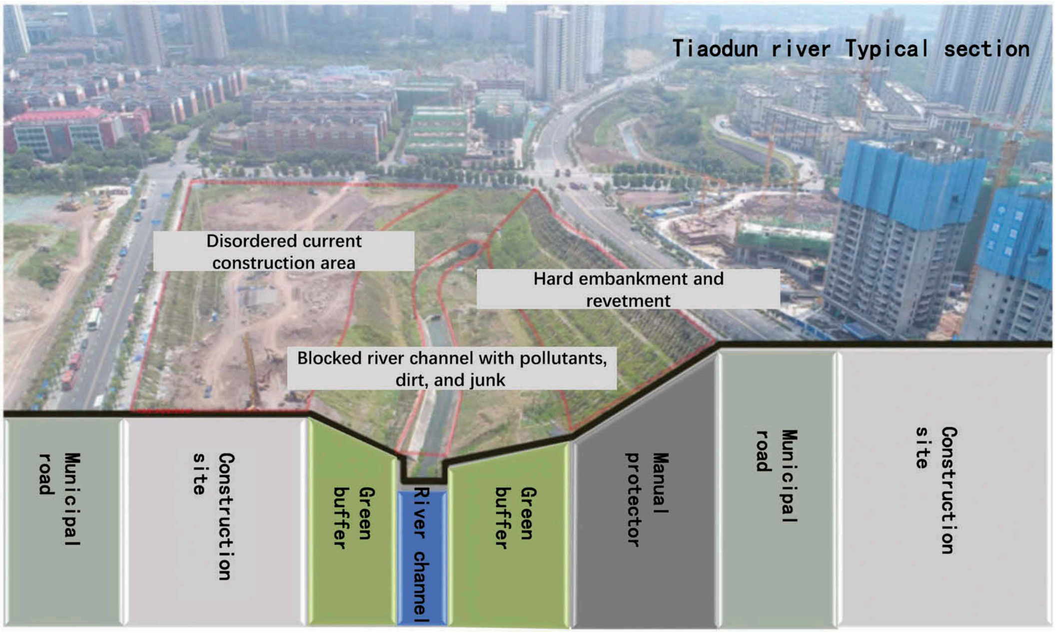

Figure 6. Typical cross-sections of the Tiaodun rivers.

maintain long-term stability of water self-purification, cooperating with supplement water engineering and sectorial running water circulation projects. Moreover, shoreline landscape planting projects were completed, and the landscapes on both sides were improved. Finally, intelligent operation and precision management were realized by the prudent control project, and new technology and equipment, such as the unmanned ships.

Sewage collection system

A total of 83 sites in the Tiaodun river were reconstructed with the sewage collection project, and the length of the new pipes was 4088 m; 10,600 m^3/d of the sewage was reduced. For the Xiaojia river, 145 wrong connections of pipes were reformed, and the length of the new pipes was 4412 m; 21,000 m^3/d sewage was reduced. The pipes were repaired for different levels of structural defects. For the Tiaodun river, the length of endoscope pipes was 80 km, and 5580 m of pipes had level II to level IV structural defects. While, for the Xiaojia river, it was 73 km and 2871 m, respectively.

Rainfall-runoff pollution control

A total of 5295 wetlands were built in the area of the two rivers, and nine first-drop reservoirs were built with an area of 15,900 m^3. Thirty-four hydro-vortex separation wells were also constructed. For the Xiaojia river, in terms of surface runoff pollution control, an 1800-m ecological grass planting ditch with a width of 1.0 m was adopted to introduce constructed wetland and submerged wetland according to the terrains. In terms of

Table 2. The main contents of the river background survey.

Project	Content	Work details
Water environment survey	Pipeline tracing	Site survey, pipeline tracing and water source identification (point source pollution, non-point source pollution and internal pollution)
	Endoscopic survey	External exploration, peeping inside box and culvert, peeping inside pipeline (investigation on structural defects of pipeline)
	Water quality and quantity survey	Continuous flow monitoring, water quality testing, arrangement of monitoring points, acquisition of effective samples, multi unit and multi batch test data
Water resources survey	Rainfall and evaporation	According to the data of weather station for nearly 10 years
	Basin reservoir characteristics	Regulating function of reservoir
	Ecological basic flow	Study and investigation of ecological base flow by Tennant method
Water ecology survey	Aquatic plant	Submerged plants, erect plants, floating plants
	Aquatic animals	Fish, shellfish, benthos, plankton
	Wetland ecology (water depth 5 m – submerged area)	Wetland biodiversity
	Terrestrial Ecology (dry all year round)	Terrestrial biodiversity
Shoreline survey	River shoreline	Typical section of shoreline (wide, narrow, steep and gentle), proportion of concealed culvert, depth of box culvert covering soil
	Closure of reservoir shoreline	Investigation on the opening length and closure of the reservoir shoreline
Water safety survey	River – related construction, structures	Barrage, box culvert, viaduct, railway bridge, river crossing pipeline
	Dam safety evaluation of reservoir	Safety of flood resistance, seepage behavior, structure behavior, seismic behavior, metal structure behavior
	Flood discharge capacity assessment	The river basically meets the 100-year flood control standard, and the reservoir meets the fortification standard (once in 20 years design, once in 200 years check)

the measures to control the drainage of rainwater, the first-drop reservoir with a volume of 1100 m^3, and a magnetic coagulation device of 5000 m^3/d, located in the drainage of rainwater of medium and large flows, were set up. In addition, the internal water treatment processing of the reservoirs after the rains and the treatment of the overflow combined sewage from the drainage of rainwater on rainy days were increased. A hydro-vortex separation well and a constructed wetland with an area of 1400 m^2 were set up at the discharging sites of the low-flow water.

Endogenous pollution control

The endogenous control was set mainly for the reservoirs. As most reservoirs are closed and half-open, and highly sensitive, the methods of in situ block and modified in situ were adopted without changing the flood regulating capacity and influencing the flood control. Manual plus excavator dredging was found better for the river channels, while manual plus mechanical equipment was good for the box culvert. First, the closure is carried out at the culvert portal, the water in the river channel is pumped to dry, then it is manually entered into the box culvert, washed with a high-pressure water gun, and the precipitated sludge is diluted. Finally, it is transported to the sedimentation tank outside the box culvert portal by the mud pump, and then the sludge is dug out by the mud boat.

For example, take the case of the Changtiangou reservoir; it was divided into three parts: (1) A moderate sediment pollution area, with an average silt depth of 1.0 m and a silt volume of 17,649 m^3. The reservoir was covered with sediment, extending an area of 17,655 m^3 and a depth of 1.0 m. (2) A mid-sediment pollution area, with an average silt depth of 0.9 m and silt volume of 11,430 m^3. With the method of sediment improvement, an area of 13,300 m^2 was amended. (3) A tectonically submerged and constructed wetland area, with an area of 4368 m^2, and the earth volume of the attached external fill is 7473 m^3.

Ecological restoration and habitat protection

Ecological restoration is usually achieved by restoration of habitats and improvement of biodiversity, to complete the food chains and ecosystems and maintain the long-term stable self-purification functionality of the water. The main ways of doing this are as follows:

(1) To strengthen the self-purification ability of the water, construct submerged and subsurface flow wetlands. For example, the Xiaojiagou reservoir had a submerged wetland with an area of 17,961 m^2, and the planting methods were traditional planting and grille plate planting (Figure 7). Grid plate planting has good air permeability, the higher survival rate of plants, and can effectively control the wild growth of plants, but the corresponding cost of traditional planting is higher, so the two methods are adopted to jointly enhance the self-purification ability of water.

(2) To build complete food chains in the ecosystem, first, inoculate high-efficiency microbial combinations in constructed wetland fillers to promote dominant high-efficiency microbial population. For example, more than 15 species of microalgae and cryptophyta were inoculated to maintain the algal diversity in the reservoir and repair the phytoplankton diversity. After 10–15 days of inoculating algae, zooplanktons were required to be inoculated to enhance the utilization rate of algae, improve the diversity of zooplankton species, and reduce the risk of water bloom. In this case, zooplankton populations containing 10 species of rotifers, 5 species of amphipods, and 3 species of rotifers were inoculated. Lastly, the introduction of

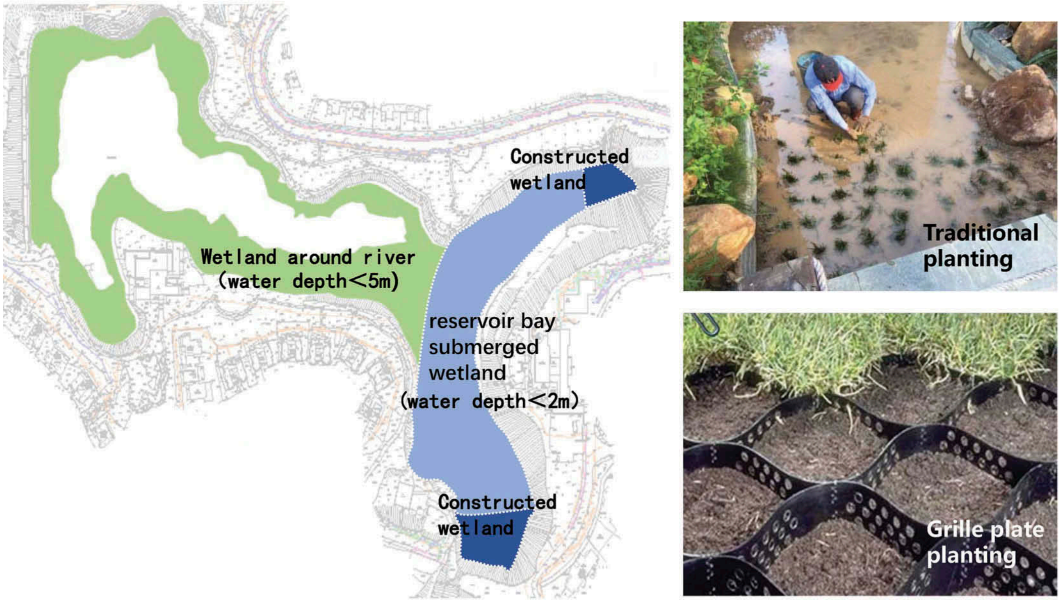

Figure 7. Construction of submerged plant wetlands in the Xiaojiagou reservoir.

benthic and other organisms suitable for growth in lakes and ponds had to be made. In this case, benthic organisms and 3 species of small snails were released within 80 cm of the water depth in the coastal zone and the shoal wetlands, and the fish structure in the reservoirs was adjusted.

(3) To circulate the running water, the reservoir power should be strengthened, with accelerated water exchange in the reservoir bay, ensuring that the surface water flow rate remained greater than 0.1 m/s. The growth of algae in the reservoir was inhibited by strengthening the material exchange. Each reservoir was constructed with a new reservoir circulation pump station, circulation pipes and bleeders, and magnetic coagulation equipment in coordination with the surface runoff control project.

Landscape greening improvement

The overall urban planning and the ecology of the rivers should be designed in advance during restoration. On the basis of investigations, it was found that the urban ecological greenways should be restored, recreational trails built, and various types of plants implanted. Interactions within the community and the facilities should also be improved so that citizenry could share the ecological benefits.

In this regard, the special design of the Tiaodun river landscape greening can be taken as an example. The land was relatively continuous; the shoreline was wide, and the public participation was high. The upstream and downstream areas were designed into a series of theme parks based on specific conditions, forming the urban blue-green park belt and creating a blue-green ecological belt that nurtured both the environment and humanity.

In the upstream of the Xiaojia reservoir, there were many weeds and a few footpaths. The focus was on improving plant growth and the footpath system. In addition, the public needed to have intimate contacts with the newly constructed wetland underwater forest, combining with the habitat. The popularization of science had to be given priority and display boards needed to be set up to enhance public awareness on environmental protection (Figure 8). The Changtiangou reservoir was backed by the Zhaomushan forest park without footpaths or habitats, and the shoreline was surrounded by the hard, retaining wall of the villa community. The footpath system leading to the side of Zhaomushan was improved to connect the footpaths, restore the habitat, and to enable the public to enjoy the beautiful view.

In the midstream of the Kangtian river, there was much-uncovered soil. In order to cover the culvert and improve the flora, a cherry blossom theme garden was built and the trail system was improved. In the midstream of the Kangzhuang river, bare soil existed without a footpath, but the riverbed condition was good and relatively wide. Combined with the construction concept of the Sponge city, the theme garden of Baitang was built with cascade stagnation, a constant flow of water streams, and full greening and a lot of plants, making it a good place for the public to enjoy the waters (Figure 9).

The downstream of the Tiaodun river had a wide view and precious and rare landscape resources. It was full of uncovered soil, thus leading to soil erosion and no trails, and the citizens' inability to enjoying the view. Therefore, ecological restoration was needed, so was an observation deck or viewpoint from where the Jialing misty rain could be viewed. This was achieved by combining the characteristics of river mist to the mountain city landscape overlooking space, comprising of the mountain, water, city, and the bridge.

Figure 8. Before and after the reconstruction of wetland on the north side of the Xiaojiagou reservoir.

Figure 9. Before and after the reconstruction of Kangzhuang river in the midstream of the Tiaodun river.

Prudent management of the watershed

Prudent river control was achieved by source control and sewage collection, rainwater runoff control, endogenous control, ecological restoration, and different engineering measures. This led to a reduction in COD,[2] ammonia, nitrogen, and TP levels, as per the expectations. The water of the whole river area met the water quality standard of class IV. At the end, it also became necessary to do intelligent control of the rivers, with advanced technologies such as artificial intelligence and big data to establish a mathematical simulation system, monitor the hydrological water quality and rainfall, etc., and use new equipment such as unmanned ships to conduct real-time monitoring and online detection of the whole water area during all weathers and with long-endurance, which is convenient, flexible, and ecologically friendly.

Conclusions

River ecological restoration in China started rather late; the value of the rivers was more for its economy and less for their ecological impacts and landscaping. The repair technologies and success levels for degraded rivers were also not many. How to protect and restore the rivers and reconstruct their ecosystems and the landscape continuity was a very important question that needed attention. These are going to be the important tasks in river conservation and restoration in the future, as well. (Ni & Liu, 2006)

In recent years, China has made great efforts to develop river ecological restoration. However, but the actual river regulation and restoration work are mostly guided by the ecological environment problems and promoted by the special remediation project of pollution control, lacking the planning level of the leading design and practical experience, which often lead to problems such as single restoration goal, blind restoration practice, and unreasonable connection of restoration work. This study explored the comprehensive water environment improvement project of the Xiaojia and the Tiaodun rivers in Chongqing. Systematic methods and a well-designed overall plan were put forward based on the investigation of sewage collection and source control, ecological restoration, landscape improvement, and the prudent control system for the implementation of method and path planning. We integrated the work contents of each department and explained the specific tasks of each link. Our study provides theoretical guidance and help for river water environment management, landscape ecological restoration, operation and construction management in built-up areas of Mountainous Cities.

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[2]COD: Chemical Oxygen Demand.

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