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Integrated river restoration in a mountainous city and case study

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Abstract

The river in a mountainous city is usually confronted with problems of short flood response time, water shortage in the dry season, artificialization of river channel, and shortage of hydrophilic spaces. Besides traditional requirements of flood control and drainage, the urban river also has functions of providing habitat, landscape, and recreation. We developed an integrated plan for river restoration in a mountainous city, based on the concept of safe, near natural, and convenient to enjoy water. We carried out case study of the Jiangshui River in Longkou City, Shandong Province, considering integrated aspects of flood control, water resources allocation, environmental protection, ecological restoration, and river landscape. Flood security was assessed by applying one-dimensional hydraulic model. Base flow was estimated, and it was maintained in the dry season by water saving in upstream irrigation areas and reuse of treated water. Water quality could be improved by increasing the collecting capacity of waste water. The low flow channel was meandering in the channel with water falls to increase habitat diversity and accessibility to water. The flood land was vegetated and constructed for citizens to enjoy water. The restoration project in the Jiangshui River was executed from 2013 to 2014. This study can help accumulate experiences of urban river restoration especially for the river in mountainous cities.

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Keywords: Urban river; River restoration; Integrated management; Longkou City

1. Introduction

River is an important link that connects the socioeconomic system and natural ecosystem in an urban area. Previously, the management of the urban river in China mainly focused on flood control, drainage and water resources exploitation, while their ecological conservation was neglected. Conventional patterns of river

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development, like artificial river channel and construction along coastal belt, have changed the natural landscape of river channel, degraded water quality, damaged habitat, and led to ecological imbalance, monotonous landscape and deficiency of enjoyable water bodies. This has severely affected the urban sustainable development and quality of habitable environment. With the rapid development of urbanization and people's living requirements, the conventional engineering concept and technology are not satisfied yet. Urban river management should not only meet the demand for flood control, but also should have functions of purifying water, providing habitat and recreation areas for people.

Therefore, domestic and abroad scholars considered the comprehensive functions of urban rivers, proposed eco-friendly ideas for urban river management and brought it into practice. The western countries realized the importance of water controversy facilities. A core object of the management of most river ecosystems was to maintain their ecological integrity [1-2]. Conservation and restoration of the natural river ecosystem were highlighted. Urban rivers were planned to play integrated functions. In 1938, Seifert proposed a concept of near natural management of rivers and streams. In the 1950s, the concept of near natural river management was implemented in Germany. River channels was vegetated and restored from artificial construction. Plants were used as engineering materials. The objectives of near natural river channel management were to meet people's utilization of water resources and to maintain or preserve the ecological diversity of rivers [3]. These concepts for an integrated river management were applied widely by Japan, and European and American countries as well, and wonderful achievements were obtained [4-5]. In early 1990s, Japanese implemented the plan for creating a diverse natural rivers and streams [6-7]. They considered watersheds, riverine space and residential communities as an organic entity. Also, they believed that the objectives of river management should include water flow, water quality, river ecosystem, water cycle, riverine space, and the relation between rivers and residential communities along riverside. In terms of river channel engineering, Japanese tended to manage river environment, restore water quality and maintain the diversity of landscape and ecosystem by using eco-friendly engineering methods.

In recent years, the understanding of Chinese scholars with regards to the concept of urban river management is being developed, and some ideas have been explored and used in the restoration of Chinese rivers. Chang et al [8] proposed a model for the reconstruction and ecological restoration of urban rivers in arid area, i.e. replacement of water by vegetation, when managing the segment of Hutuo River flowing through Shijiazhuang city. Wang et al [9] discussed the construction of an integrated river ecosystem (the so-called five-in-one river ecosystem) with Lianyungang city as an example. Liu [10, 11] suggested a natural, accessible and cultural concept for urban river management. Chen et al [12] proposed the natural-accessible-cultural meaning of urban rivers and assessment index system, and brought it into practice. Gao et al [13] argued that near natural urban river management should consider its multiple objectives, ecological protection, aesthetics and cultural conservation. Nevertheless, no uniform requirements and regulations for river restoration engineering plans are available as yet. Considering the diverse natural geographical conditions and levels of socioeconomic development, to develop the advanced concept of urban river management, it is necessary to adopt different urban river management model depending on the conditions of different watersheds and regions.

Urban rivers in a mountainous watershed are usually characterized by relatively higher gradient of river channel, instant rise and drop of flood level, water resources shortage, obvious dry and wet seasons and limited environmental capacity. Such issues interact with intense urban land, waste water discharge and scarcity of accessible river space. Meanwhile, the mountainous watershed usually lacks of monitoring information of hydrology, water quality and ecosystem. During the fast process of urbanization, less attention has been paid to river protection. The river channel was sometimes subjected to meander cut-off, rechanneling and artificial hardening. Therefore, in the context of rapid urbanization and increasing demand for ecological protection in China, urban river management in mountainous watershed has become a general problem to be faced during urban development. In this paper, we proposed a feasible model for integrated urban river management in mountainous watershed with the Jiangshui River, Longkou city, Shandong Province, as an example. Our results will supply experience to urban river management. It will also be meaningful for urban river management of similar watersheds.

2. Study area

The Jiangshui River is located at east Longkou City, Shandong Province (Fig.1). It originates from the north piedmont of the Xinghua Mountain in Longkou City. The Jiangshui River flows through Dongjiang Town, Donglai Town and Zhuyouguan Town from south to north. The water converges with the Huangshui River and flows into Bohai Sea. The drainage area of the Jiangshui River is 111.6 km^2 (area in the city zone and upper reaches is 34.6km^2). The total river length is 20.7 km and the river reach in Longkou city is 3.5 km. The average annual precipitation is 582 mm, and 70% precipitation occurs during June to September. The average annual runoff is 2.064×10^7 m^3. There is a small reservoir in the upper reach of the city, named Beilu Reservoir which controls a drainage area of 11.4km². The total storage of this reservoir is 1.04×10^6 m^3, and the effective capacity is 5.6×10^5 m^3.

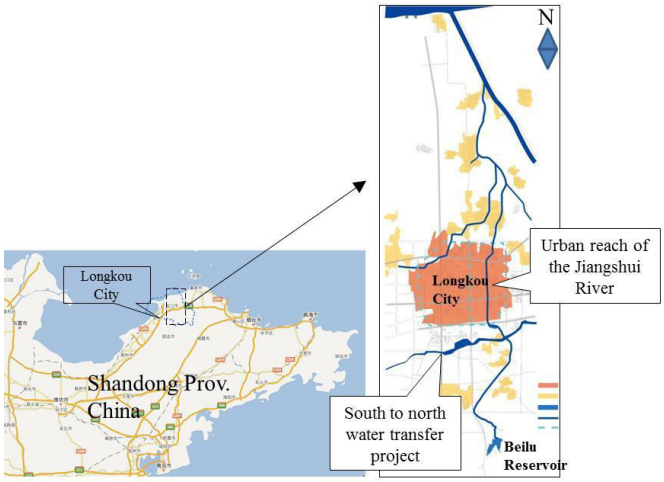

Fig. 1. Study area.

Jiangshui River is an important river that flows through the east city zone of Longkou City. In 1979, the meanders of Jiangshui River in Longkou city were cut off, and straight masonry embankment was built. In recent years, insufficient attention has been paid to the maintenance of embankment and river channel. Some problems have become obvious during the process of urbanization.

(1) Some parts of the river channel were filled up by deposit. Bridges severely blocked river flow. The capacity of flood discharge was decreased.
(2) Water resources were in severe shortage. The river channel lacked basic flow during dry seasons.
(3) Both banks were combined drainage systems of rainfall and wastewater. Part of the wastewater flowed directly into the river. Rubbish was piled up randomly, and the river was severely polluted.
(4) River channel was straight, monotonous and rigid. The banks were hardened. Green lands at both banks were isolated by iron fences. It was hard for residents to access to the river. Enjoyable aquatic space and places for entertainment and physical training were insufficient (Fig. 2).

Fig. 2. The urban reach of the Jiangshui River before restoration.

3. Concept and methods of river integrated restoration

3.1. General concept

To enhance flood control capacity and to improve quality of unban river environment, an integrated restoration project was conducted in the urban reach of the Jiangshui River in 2013 and 2014. Water management has been changed from a singular to a systemic management. An integrated restoration that taking safety, environment, and landscape into consideration has been implemented based on the philosophy of safety, nature, enjoyment and civilization. The purposes were to ensure the safety of flood discharge, implement near natural restoration, promote the harmony between human and water, shape enjoyable aquatic landscape, and to improve the quality of living environment.

3.2. Restoration method

The restoration project covered a 3.5km long urban river reach of the Jiangshui River. Because the river in the city zone was confronted with problems of flood risk, insufficient wastewater interception of both banks, artificial river channel and monotonous landscape, integrated restoration measures were carried out. On the basis of the safety of flood discharge, the basic flow in river channel would be maintained. The capacity of wastewater interception was increased. The low flow channel was meandering in the channel with water falls to increase habitat diversity and accessibility to water. The flood land was vegetated and constructed for citizens to enjoy water. The urban river will provide safe and comfortable riverine space for urban residents.

3.2.1 Ensure the safety of river channel during flood discharge

We analyzed and calibrated the flood discharge capacity of the urban river reach of the Jiangshui River. We constructed a one-dimensional hydraulic model by using the topography of river channel and the Mike 11 software, in combination with on-site investigation. During model construction, computing sections were placed with the interval distance of 200m. The computing sections were increased at the upper and lower reaches of bridges. We calculated and analyzed the flood discharge capacity of 20 year flood and 50 year flood. The results showed that, in order to meet the requirement for flood discharge of 50 year flood, the height of banks should be increased by 0.2m from Nanshagou Bridge to the 100m upstream, from Linjiazhuang Bridge to 200m upstream, and from Dongshichang Bridge to 100m upstream.

3.2.2 Maintain basic flow during the dry season

There is no hydrological station on the Jiangshui River. The drainage area of the upper river reaches of Longkou City was extracted based on the DEM data. We calculated the annual runoff (m^3) in wet and dry years depending on the runoff depth (mm). The average annual runoff is 4.92×10^6 m^3. The annual runoff in dry years (p=75%) is 2.42×10^6 m^3. The annual runoff varies obviously among dry and wet years, and there are less water storage projects. At present, the main water conservancy facility is Beilu reservoir. The reservoir supplies water to orchards and farmlands. The irrigation area is 15.6 hm^2. According to the quota for irrigation in Shandong Province (Standard number: DB37/T1640-2010), the irrigation water demand is 4.7×10^5 m^3 for normal years (p=50%), while that for dry years (p=75%) is 6.5×10^5 m^3.

Based on the situation of current water conservancy facilities, it is not enough to maintain the basic flow of the Jiangshui River. In this paper, we analyzed the quantity of basic flow, and proposed a possible water sources. The area of the upper river basin of the city is 34.57 km^2, and the average annual flow rate is 0.2m^3/s. According to the Tennant method, the basic flow in river channel is 0.1m^3/s. The runoff in river channel is abundant during the wet season, so the water for landscape requirement can be satisfied (Fig. 3). During the dry season, from December to March in normal years, and from November to April in dry years (p=75%), the monthly mean flow rate is below 0.1 m^3/s. In particular, it is the ice period from the third ten days in December to the first ten days in February.

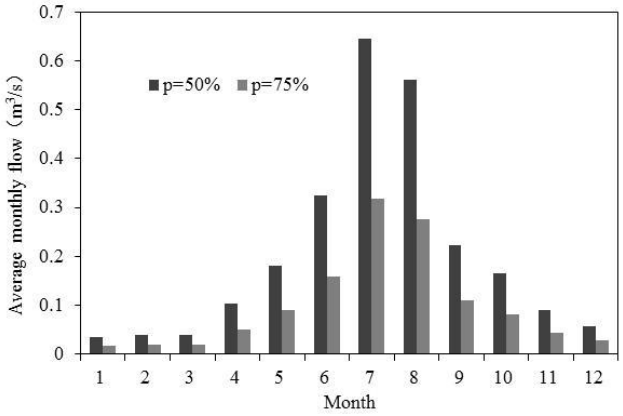

Fig. 3. Average monthly flow in the urban reach of the Jiangshui River.

Therefore, the basic flow from February to April should be supplemented by artificial projects. To maintain the basic flow of 0.1 m^3/s, the quantity of water demand is 5.0×10^5 m^3 in the normal year (p=50%), and 8.8×10^5 m^3 in and the dry year (p=75%). The basic flow is supplied mainly from water conservation in the upper river basin and reuse of treated water.

(1) If farmlands at the lower reach of the Beilu Reservoir are irrigated in a sprinkling or micro-irrigating manner, water demand for irrigation would be reduced to 3.3×10^5 m^3. In this case, there will be 2.3×10^5 m^3 water in the Beilu Reservoir available to supply the basic flow.

(2) Application of water reuse in the city zone can meet the demand for basic flow in river channel. There are 130 000 people in the city zone where the Jiangshui River flows through. The wastewater produced will be 1.56×10^4 m^3 per day, assuming that water consumption per capita is 150L and that the discharge coefficient is 0.8. Through the application of piping project of water reuse, treated water at the lower reach would be transferred to the upper reach from the wastewater treatment plant. The designed quantity of water supply is 9.0×10^3 m^3/d, and the annual amount will be 3.28×10^6 m^3. The water supply for basic flow can be satisfied.

3.2.3 Increase waste water collection capacity and management level of environment protection

There is a combined drainage system of rainfall and wastewater in the city along the Jiangshui River. Although each bank has its own system, the intercepting capacity at some parts of the system is insufficient. Sewage that excesses the capacity is directly discharged to the river. The rubbish is piled up randomly. The public awareness of environment protection remains to be improved. The current water quality is class V (the worst class according to the Chinese national environmental quality standard of surface water, GB 3838-2002). The managing strategies include 1) to improve the system for rainfall and sewage collection, increase sewage collection capacity, collect all of the wastewater during non-flood period, and to discharge the rainfall and wastewater into river during flood period when the intercepting capacity has been saturated. 2) to maintain the basic flow in river channel and improve the self-purification capacity. 3) to establish a system for riverine rubbish sorting and cleaning, and intensify public participation and education.

3.2.4 Create near natural water flow and enjoyable landscape

Considering that the reaches of the Jiangshui River flowing through the city zone is featured by steep gradient of riverbed, unstable embankment, insufficient water source, water pollution and shortage of enjoyable aquatic spaces, it is unsuitable to form artificial lake landscape by water storage projects like rubber dams. The Jiangshui River is a seasonal river. In most time of a year, the flood land in the river channel is dry. It thus can provide the surrounding residents with multifunctional spaces for entertainment, physical activities and affinity to nature. Meandering trait is the innate nature of rivers. Therefore, a compound section is adopted. The main low flow channel is dominated by meandering current together with 0.3 m high cascading hydraulic drops. The flood land is vegetated. A consecutive walking system and areas for riverine entertainment and physical training are built. This strengthens communications between both banks and the river. It enhances the accessibility of riverine spaces, and supplies enjoyable aquatic spaces for urban residents.

3.3. Outcome of the river restoration project

The integrated restoration project of the Jiangshui River in Longkou city was completed at June, 2014 (Fig.4). After that, the embankment of Jiangshui River can defend the 50 year flood in the city. The natural features and landscape diversity of river channel was improved. It provides convenient enjoyable water environment for surrounding residents. People enter the river channel for physical training and entertainment. The quality of human habitation environment near the river is improved.

Fig. 4. The urban reach of the Jiangshui River after restoration.

4. Conclusion

The urban river in a mountainous watershed in China is usually featured by short response time to flood, prominent variation of flow discharge in the dry and wet seasons, insufficient basic data and artificial river channel. This paper proposed an integrated river restoration mode in terms of its safety, resources, environment, and landscape, with the Jiangshui River, Longkou city, Shandong Province as an example. The Jiangshui River was restored to be more natural. On the basis of flood discharge safety, the basic flow in the low flow river channel was supplied by upstream water conservation, reuse of waste water. With a compound section, the low flow was meandering in the river channel with hydraulic drops. The flood land was vegetated to be a river park. Riverine walking system and places for entertainment and physical training were built. The project supplied enjoyable aquatic space to residents and improved the quality of living environment. It could be referenced by similar urban river restoration projects.

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