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River ecosystem assessment and application in ecological restorations: A mathematical approach based on evaluating its structure and function

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ABSTRACT

The river is an essential part of water resources, which has unique ecological structure and function. With the rapid socio-economic development, the improper use of water resources has led to a series of structural and functional decline of the river system, such as water pollution, environmental degradation and river shrinkage. How to restore damaged river ecosystems to an ecologically healthy status has become one of the important environmental issues, which is the key to achieve the goal of productivity improvement, ecosystem balance and sustainable development. And also, the structure and function of the river ecosystem should be pre-assessed before the restoration. In this paper, the Liangshui River, a tributary of Daling River in the arid region of western Liaoning Province, is selected as a study site. An assessment index system involving 21 defined indices on structure and function of river ecosystem is firstly established. A mathematical method for comprehensive assessing the structure and function of river ecosystem is proposed based on the Set Pair Analysis (SPA) and Quadrant Method. Then, the evaluation value is gained at the ecosystem level. The result shows that the assessment value of structure and function is −0.513 and −0.208, respectively, which means that the Liangshui River ecosystem is defective in structure and sub-healthy in function. It is necessary to choose potential development emphasized on the structurally rehabilitating of the Liangshui River ecosystem. Based on the above, ecological engineering measures and suggestions are recommended to preserve the health of river ecosystem.

1. Introduction

As an important resource and environment carrier, the river works as shelter and food source for an array of biological species, and aiding in flood management and ecological refuge development (Pinto and Maheshwari, 2011). With the rapid development of society, human disturbances on the river extend. Water conservancy projects bring great social benefits, but also lead to stress effect on the river ecosystem inevitably. Rivers have been channelized, diverted, straightened and corseted in levees, with little or no thought for river dynamics and biodiversity preservation (Poulard et al., 2010). Furthermore, a huge amount of industrial and agricultural pollutions from human activities were put into rivers. The emergence of series of structural and functional decline of river system, such as water environment deterioration, biodiversity loss and ecosystem degradation, has eventually resulted in the unbalance between natural features and socio-economic functions of rivers.

How to restore damaged river ecosystems has raised wide concern from hydrologists, stream ecologists and watershed managers. It is found that the assessment of river ecosystem defect is the prerequisite for ecological restoration, which could provide theoretical foundation for river management. There are a large number of empirical studies on assessment of river ecosystem health (Liu and Liu, 2009; Zhao and Yang, 2005), analysis of river service function (Xiao et al., 2006; Zhou and Xiao, 2010), discussion of ecosystem restoration (Li and Ju, 2005; Pei et al., 2013). The current research, however, rarely focuses on the holistic method and process of river ecosystem protection and restoration based on the assessment of its structure and function. Dong (2008) developed a conceptual model, describing the structure and function of river ecosystem. The assessment of river ecosystem was studied earlier

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abroad, and more research concentrated on a biological community via its features, changes and the feedback mechanisms to reflect the health of river ecosystem (National Research Council, 1992; Lansing et al., 1998; Lakly and McArthur, 2000; Bain et al., 2000; Gallardo et al., 2011; Ramos et al., 2012). There are a great amount of evaluation methods including fuzzy method, grey system theory, matter element analysis method, principal component analysis. Although these approaches have been applied to some extents in the comprehensive evaluation field, common defects exist such as their complexity, difficulties in the implementation and application. Along with the study and experiment of assessment for river ecosystem, it is necessary to find an appropriate technical method of simplicity and effectiveness. In this context, a mathematical method for comprehensively assessing the structure and function of river ecosystem is developed.

The northwest area of Liaoning Province is a representative region with serious water shortage. In order to completely solve this problem, a large scale of the water diversion project for northwest of Liaoning has been adopted. Water is transported to Baishi Reservoir, and then diverted to Chaoyang, Fuxin, Tieling, Jinzhou and Huludao City, which effectively supporting the strategy of "Breakthrough Northwest of Liaoning". As an important direct inflow of Baishi Reservoir, the Liangshui River drains a broad area with large number of resident population and industrial enterprises. It has become a significant target to protect water quality and to preserve the drinking water source of the Baishi Reservoir. In this research, the Liangshui River, a tributary of Daling River, is selected as a study site. Based on the quantitative evaluation of the structure and function of Liangshui River, this paper proposes measures for the river ecological restoration. The main goal of this study is to provide basis on the comprehensive management of the Daling River. Meanwhile, it can not only be applied to small and midsize rivers for researchers, engineers and managers, but also to create a positive suggestion for protection and restoration of the local river ecosystem.

2. Methods

2.1. Set Pair Analysis (SPA)

The river ecosystem is a highly complex system with multitudinous influential factors, involving many aspects. It is not easy to estimate the status of river ecosystem for multiple and uncertain characteristics. Set Pair Analysis (SPA) is a system theory using a connection number to process the uncertainty caused by fuzzy, random and incomplete information uniformly. Considering symmetry information from identity, discrepancy and contrary, SPA is simple in concept and convenient to calculate. As a useful tool in uncertainty theory, SPA can analyze the inner relations of the research system, which has been widely applied in many fields (Wang et al., 2009; Su et al., 2009). This paper introduces SPA in the study to measure river ecosystem.

SPA was proposed by Zhao (1989) based on the point of view in unity and opposition. The core procedure of SPA is combining set A and B to construct a certain-uncertain system as a set pair whose properties are analyzed by means of identity, discrepancy and contrary. The connection degree of set pair could be established according to the three aspects. There are N characteristics can be obtained. S, P and F are the number of identical, contradictory and discrepant terms of characteristic. The connection degree of set A and B is defined as follows:

$$\mu_{AB} = \frac{S}{N} + \frac{F}{N}i + \frac{P}{N}j = a + bi + cj \tag{1}$$

where μ_{AB} is the connection degree; i is the uncertainty coefficient of discrepancy having different values in [−1,1] or sometimes as a marker of discrepancy only; j is the uncertainty coefficient of contradictory with the value of −1 or sometimes as a maker of contradictory only; S/N, F/N and P/N is called identity, discrepancy and contradictory degree, namely a, b, c and $a+b+c=1$.

According to an actual research demand, the connection degree can be extended from three elements to four or five and more. The expression of multi-element connection degree can be written as:

$$\mu_{AB} = a + b_1 i_1 + b_2 i_2 + \cdots + b_{k-2} i_{k-2} + cj \tag{2}$$

where b_1, b_2,···, b_{k-2} are called the components of discrepancy degree explained as the different grades of the discrepancy degree, and $a+b_1+b_2+\cdots+b_{k-2}+c=1$; i_1, i_2,···, i_{k-2} are uncertainty components coefficient of discrepancy degree.

A membership function is established to quantitatively describe the relationship from the three aspects of identity, discrepancy, and contrary. Assessment indices can be divided into cost-type and benefit-type. The connection degree formulas are represented as Eqs. (3) and (4), respectively:

Cost-type index:

$$\mu_l = \begin{cases} 1 + 0i_1 + 0i_2 + \cdots + 0i_{k-2} + 0j & (x_l \le s_1) \\ \dfrac{s_1 + s_2 - 2x_l}{s_2 - s_1} + \dfrac{2x_l - 2s_1}{s_2 - s_1} i_1 + 0i_2 + \cdots + 0i_{k-2} + 0j & \left(s_1 < x_l \le \dfrac{s_1 + s_2}{2}\right) \\ 0 + \dfrac{s_2 + s_3 - 2x_1}{s_3 - s_1} i_1 + \dfrac{2x_l - s_1 - s_2}{s_3 - s_1} i_2 + \cdots + 0i_{k-2} + 0j & \left(\dfrac{s_1 + s_2}{2} < x_1 \le \dfrac{s_2 + s_3}{2}\right) \\ \cdots & \\ 0 + 0i_1 + \cdots + \dfrac{2s_{k-1} - 2x_l}{s_{k-1} - s_{k-2}} i_{k-2} + \dfrac{2x_l - s_{k-2} - s_{k-1}}{s_{k-1} - s_{k-2}} j & \left(\dfrac{s_{k-2} + s_{k-1}}{2} < x_l \le s_{k-1}\right) \\ 0 + 0i_1 + 0i_2 + \cdots + 0i_{k-2} + j & (x_l > s_{k-1}) \end{cases} \tag{3}$$

Benefit-type index:

$$\mu_l=\begin{cases}1+0i_1+0i_2+\cdots+0i_{k-2}+0j & (x_l\geq s_1)\\ \dfrac{2x_l-s_1-s_2}{s_1-s_2}-\dfrac{2s_1-2x_l}{s_1-s_2}i_1+0i_2+\cdots+0i_{k-2}+0j & \left(\dfrac{s_1+s_2}{2}<x_l\leq s_1\right)\\ 0+\dfrac{s_2+s_3-2x_l}{s_3-s_1}i_1+\dfrac{2x_l-s_1-s_2}{s_3-s_1}i_2+\cdots+0i_{k-2}+0j & \left(\dfrac{s_2+s_3}{2}<x_l\leq\dfrac{s_1+s_2}{2}\right)\\ \cdots & \\ 0+0i_1+\cdots+\dfrac{2x_l-2s_{k-1}}{s_{k-2}-s_{k-1}}i_{k-2}+\dfrac{s_{k-2}+s_{k-1}-2x_l}{s_{k-2}-s_{k-1}}j & \left(s_{k-1}<x_l\leq\dfrac{s_{k-2}+s_{k-1}}{2}\right)\\ 0+0i_1+0i_2+\cdots+0i_{k-2}+j & (x_l>s_{k-1})\end{cases} \quad (4)$$

where s_1, $s_2 \ldots s_{k-2}$, s_{k-1} are standard grades; k is the assessment grade; x_l represents the measured value reflecting the assessment state.

After acquiring the connection degree μ_l between the measured value and standard, the set (A, B) of each assessment grade standard could be constructed and k-element connection degree could be obtained. The assessment model of SPA is developed as follows:

$$\mu=\sum_{l=1}^{m}w_l\mu_l=\sum_{l=1}^{m}w_la_l+\sum_{l=1}^{m}w_lb_{l,1}i_1+\cdots+\sum_{l=1}^{m}w_lb_{l,k-2}i_{k-2}+\sum_{l=1}^{m}w_lc_lj \quad (5)$$

where w_l is the weight of assessment index.

2.2. Quadrant Method

Two-dimensional Quadrant Method was originally proposed to reveal the relationship between basic science and technological innovation (Stokes, 1997). Briefly, it created 4 quadrants that separate pure basic science (X-axis) from applied research (Y-axis). The idea of using Quadrant Method has been widely applied to illustrate the relationship between two subjects in many fields, such as medical science, geographical research, as well as hydraulic engineering (Krajewski and Chandawarkar, 2008; Price and Behrens, 2003; Sun et al., 2010; Dong, 2006). To identify the state of river ecosystem, two-dimensional standard of the structure and function must be used as constraint. This study uses Quadrant Method to determine the assessment zoning of river ecosystem based on the internal logical relationship between its structure and function. Referring to the thought of Quadrant Method, a coordinate can be cut into four quadrants, among them abscissa represents the structure (S), the ordinate stands for the function (F).

Combining Set Pair Analysis and Quadrant Method, the structure and function of river ecosystem is assessed and zoned based on the two-dimensional logical principle. Values ranged between −1 and 1 would be obtained by SPA. According to the principle of equipartition, the range of [−1,1] could be separated into four parts: [−1,−0.5), [−0.5,0), [0,0.5), [0.5,1]. Then, 16 cell-zones can be obtained, and each zone is represented by A_{ij}. The assessment zoning chart of structure and function for river ecosystem is developed (refer to Fig. 1).

This paper categorizes the state of structure and function of river ecosystem into three grades including good (integrated), medium and bad (defective). Thus, the 16 cell-zones can be classified into 9 areas, whose specific meanings are as follows in Table 1.

2.3. Index system and weights

The structure and function is the core issue of a river ecosystem, whose essence is the interrelation analysis between river living systems and life-support systems. Along with the study of ecological restoration, the structure and function of different ecosystems have been concerned and researched, such as lakes and wetlands. These researches, however, rarely focus on the holistic assessment and process of the structure and function of rivers. The river ecosystem is generally expressed with organisms, riparian zone, physical structure, water quality and the amount of water (Dong et al., 2010). In order to quantitatively evaluate the state of river ecosystem, this paper develops the assessment index system in terms of reference to historical information, accuracy and available resources. The index system of the structure contains water, landform, organism and other habitat factors. The functions of a river including its role in ecology, society and comprehensive benefits are considered. The proposed 21 defined indices (from X_1 to X_{21}) based on the connotation of river characteristics are shown in Table 2.

Weights should be introduced to organically unify the absolute data processing and practical problems solving. The AHP is a useful approach for multiple criteria decision making, developed by Saaty in early 1970s. The practical nature of AHP has led to diverse applications in the past three decades in solving complex, large and elusive decision problems. The AHP method follows three steps:

(i) Structure the hierarchy of attributes for evaluation;

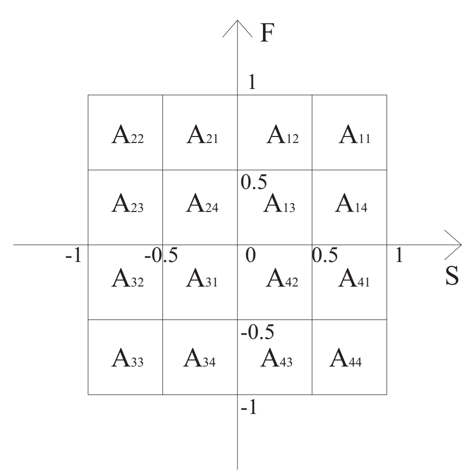

Fig. 1. The assessment zoning chart of structure and function for river ecosystem.

Table 1
The assessment zoning of structure and function for river ecosystem.

Area	Structure (S)	Function (F)	Analysis of comprehensive evaluation
A_{11}	Good	Good	The river ecosystem is good with intact structure and function.
A_{12}, A_{21}	Medium	Good	The structure is at a moderate level and the function is full.
A_{22}	Bad	Good	In this area, it is urgent to optimize the structure and restore the river ecosystem.
A_{14}, A_{41}	Good	Medium	The function is at a moderate level and the structure is integrity.
A_{13}, A_{24}, A_{31}, A_{42}	Medium	Medium	The river ecosystem is at an intermediate-level with secondary structure and function.
A_{23}, A_{32}	Bad	Medium	In this area, it is necessary to choose potential development based on the structural rehabilitating.
A_{44}	Good	Bad	The structure of river ecosystem is integrity with functional deficit. This area must be prioritized for requirements of development.
A_{43}, A_{34}	Medium	Bad	In this area, it is necessary to draw up adaptive development based on the functional adjustment.
A_{33}	Bad	Bad	The river ecosystem is bad with defective structure and function.

Table 2
Summary of assessment indices for the river ecosystem.

Factor	Index and description	Weight
S		
Water (S1)	Variation coefficient rate of annual runoff (X_1): the change rate of interannual variation on runoff discharge in river basin.	0.117
	Water quality classification (X_2): comprehensive assessment of the water quality in a year.	0.094
	Eutrophication index (X_3): characteristics of eutrophication including total phosphorus (TP), total nitrogen (TN), chlorophyll α (chl-α) and potassium permanganate index (COD_{Mn}) and transparency degree (SD).	0.039
Landform (S2)	Style of channel revetment (X_4): whether the revetment is natural ecological.	0.060
	Embankment bank slope stability (X_5): river bank exhibits erosion collapse or not.	0.107
	Width of riparian zone (X_6): the width of riparian buffer strip.	0.083
Organism (S3)	Vegetation coverage (X_7): the coverage of vegetation, based on the field investigations.	0.128
	Index of biotic integrity (Fish-IBI) (X_8): to reflect compositions and structures of biological assemblages.	0.090
	Index of species diversity (X_9): to reflect the richness of species.	0.032
Others (S4)	Condition of habitat (Fish) (X_{10}): characteristics of the habitat for fish.	0.167
	Connectivity of habitat (X_{11}): the connectivity of river habitat in horizontal, longitudinal and vertical dimension.	0.083
F		
Natural ecology (F1)	Satiety rate of the minimum environmental water demand (X_{12}): rate of the lowest discharge in dry season to the minimum environmental water demand of a river.	0.108
	Standard-achieving rate of the water function area (X_{13}): divide the total length of the estimated stretches by the length of the standard-achieving stretch within the water function area.	0.038
	Comfort level of the ecology landscape (X_{14}): comfort levels on the ecology landscape of the river.	0.154
Social economy (F2)	Ratio of water resources development (X_{15}): to reflect the level of water resources development for the river basin.	0.089
	Utilization coefficient of irrigation water (X_{16}): divide the total inflow of channel by consumed water of the crop.	0.137
	Output of GDP per cubic water (X_{17}): to measure the social economic benefit.	0.074
Comprehensive feature (F3)	The perfection of the flood control system (X_{18}): the present flood control system is perfect or not.	0.059
	Utilization rate of hydroenergy under ecological safety (X_{19}): the ratio of water resources development to the total volume under ecological safety.	0.131
	Satisfied degree of human activities requirement (X_{20}): whether there are leisure facilities, water loving is easy, safe or not.	0.065
	Guarantee rate of cultural aesthetics (X_{21}): the developing degree of river function in cultural aesthetics.	0.145

Note: The fish is at the top of the food chain, reflecting the status of lower-class (producers) in a river ecosystem. Thus, this paper selects fish to measure the feature of biotic integrity and the condition of habitat.

(ii) Compare the relative importance of indicators by pair-wise comparison;
(iii) Use the eigenvector method to yield weights for attribute index.

More details and formal definitions can be seen in the cited literatures (Saaty, 1980; Ho, 2008).

3. Case study

3.1. Study area

The Liangshui River is a left branch of Daling River in the northwest of Beipiao City, about 51 km long, with a drainage area of 736 km^2 (Fig. 2). It springs from Nuluerhu Mountain with two branches, meeting together in the Liangshui River Town, and finally flows into Baishi Reservoir. The Liangshui River is a typical mountainous river. There are many hills and steep slopes in the river basin, mainly at 140–1133 m elevation, and the northwest side of the catchment is higher than the southeast side. Because of poor vegetation cover, serious soil erosion, and high sediment concentration in the river, the study area has become the national-level water conservation precinct.

The ecosystem protection and restoration of Liangshui River is a vital issue to the water supply safety of Baishi Reservoir, as well as the key technical method on improving the efficiency of water diversion project for western Liaoning Province. In this paper, the structure and function of river ecosystem is firstly evaluated. Then, the combination of biological measures, engineering solution and management action for river ecological restoration is researched to get win-win situation of social and economic benefits and ecological protection.

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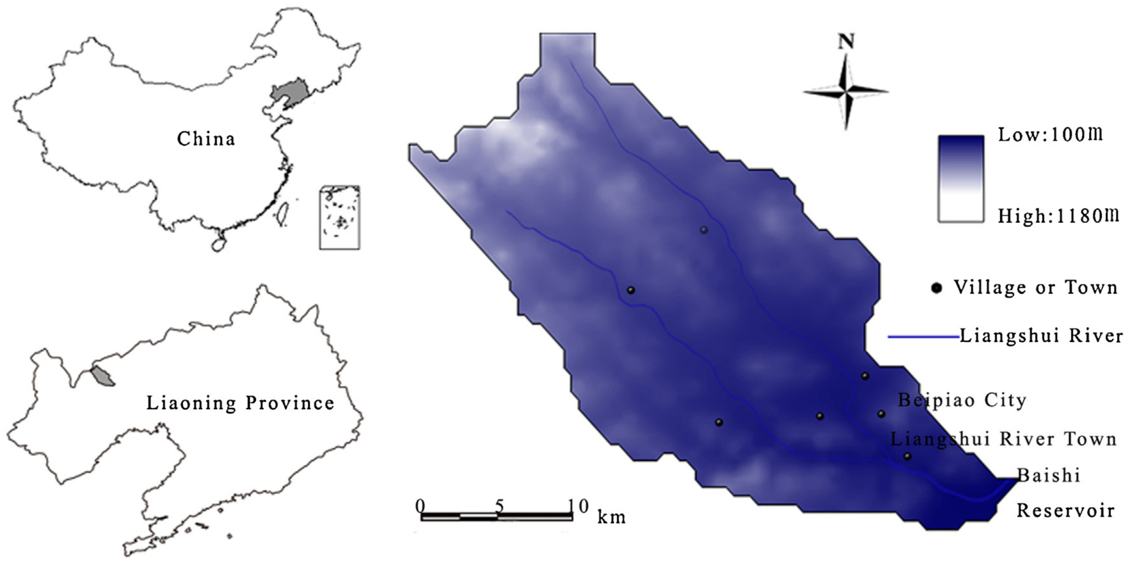

Fig. 2. Location of the Liangshui River.

3.2. Results and analysis

The study area is a section of Liangshui River from Taiji Railway Bridge (below the city defense) to the estuary of Baishi Reservoir, about 10 km long. This paper obtains data of these 21 indices from three sources: (1) Beipiao City Statistical Yearbook from Chronicles Office of Beipiao City; (2) Hydrological information and materials of the Liangshui River from Construction Office of Daling River Protection Zone; (3) Questionnaires on status of the study river basin's ecological protection and comprehensive management from local people and experts based on the spot investigation and interview.

According to AHP method, weights in index layer can be obtained as follows:

Water: $W_{S1} = (w_1, w_2, w_3) = (0.512, 0.360, 0.128)$;
Landform: $W_{S2} = (w_4, w_5, w_6) = (0.238, 0.429, 0.333)$;
Organism: $W_{S3} = (w_7, w_8, w_9) = (0.467, 0.376, 0.157)$;
Others: $W_{S4} = (w_{10}, w_{11}) = (0.667, 0.333)$;
Natural ecology: $W_{F1} = (w_{12}, w_{13}, w_{14}) = (0.360, 0.128, 0.512)$;
Social economy: $W_{F2} = (w_{15}, w_{16}, w_{17}) = (0.295, 0.457, 0.248)$;
Comprehensive feature: $W_{F3} = (w_{18}, w_{19}, w_{20}, w_{21}) = (0.148, 0.326, 0.163, 0.362)$.

Taking equal weights among factors as: $W_S = (W_{S1}, W_{S2}, W_{S3}, W_{S4})=(0.25, 0.25, 0.25, 0.25)$ and $W_F=(W_{F1}, W_{F2}, W_{F3})=(0.333, 0.333, 0.333)$. Then, weights can be got in the last column of Table 2.

Submitting weights into Eq. (5), the result of structure and function assessment on Liangshui River ecosystem is gained as follows:

$$\mu s = 0.06 i_1 + 0.087 i_2 + 0.621 i_3 + 0.232 j \quad (6)$$

$$\mu_F = 0.074 + 0.048 i_1 + 0.329 i_2 + 0.485 i_3 + 0.063 j \quad (7)$$

According to the principle of equipartition, assigning $i_1 = 0.5$, $i_2 = 0$, $i_3 = -0.5$, $j = -1$, then, values of assessment are calculated by substituting these coefficients into Eqs. (6) and (7), that is, $\mu_S = -0.513$ and $\mu_F = -0.208$. The result located in A_{32} of the assessment zoning chart, indicating that the Liangshui River ecosystem is defective in structure and sub-healthy in function. It means that the structure of the Liangshui River ecosystem has been gradually impaired due to the human activities, although the function seems to be at an acceptable level. However, it cannot meet requirements in the further development of society, economy, culture and ecology, leading to a severe impact on the biological survival of river ecosystem, living quality of the human, and development of the society. Therefore, it is necessary to choose potential development emphasized on the structurally rehabilitation of Liangshui River ecosystem rather than on the functionally rehabilitation such as water transfer and flood control embankment project.

3.3. Discussion and strategies

Beipiao City typically rose because of coal mining. On the one hand, its energy structure is dominated by coal, and low-altitude emissions of raw coal burning associated with air and water pollution. On the other hand, due to the existence of coal washing along Liangshui River, water pollution has become a very critical issue in the urban area of Beipiao City.

Monthly report of Daling River shows that the water quality of Liangshui River monitoring section is between Grades IV and V. When the contaminative loads exceed the fragile self-purification capacity, it has a negative effect on the survival and reproduction of the fish and other aquatic organism, causing biodiversity diminishes. Meanwhile, numerous construction wastes and household garbage are packed along the river bank, which intensely destroys the river eco-environment.

Based on the desirable demand of river basic function and coupled with the natural effect and less human intervention of structural and non-structural measures, the river ecosystem that can maintain biodiversity and ecological balance with excellent self-regulation and repairing for harmonious development of natural and humanistic environment, is becoming an inspiring target for the river ecological management. Responding to the above, the restoration of Liangshui River of Beipiao City ecosystem is promoted. The design area is a part of Liangshui River from Taiji Railway Bridge (downstream of the urban flood preventing project) to the estuary of Baishi Reservoir.

3.3.1. Riparian buffer strips

Riparian vegetation buffer zone is the transitional ecotone between aquatic and terrestrial ecosystem, which has unique spatial structure and functions for ecological service. According to the principle of building transitional ecotone, the riparian buffer strip along Liangshui River below the city defense, with a length

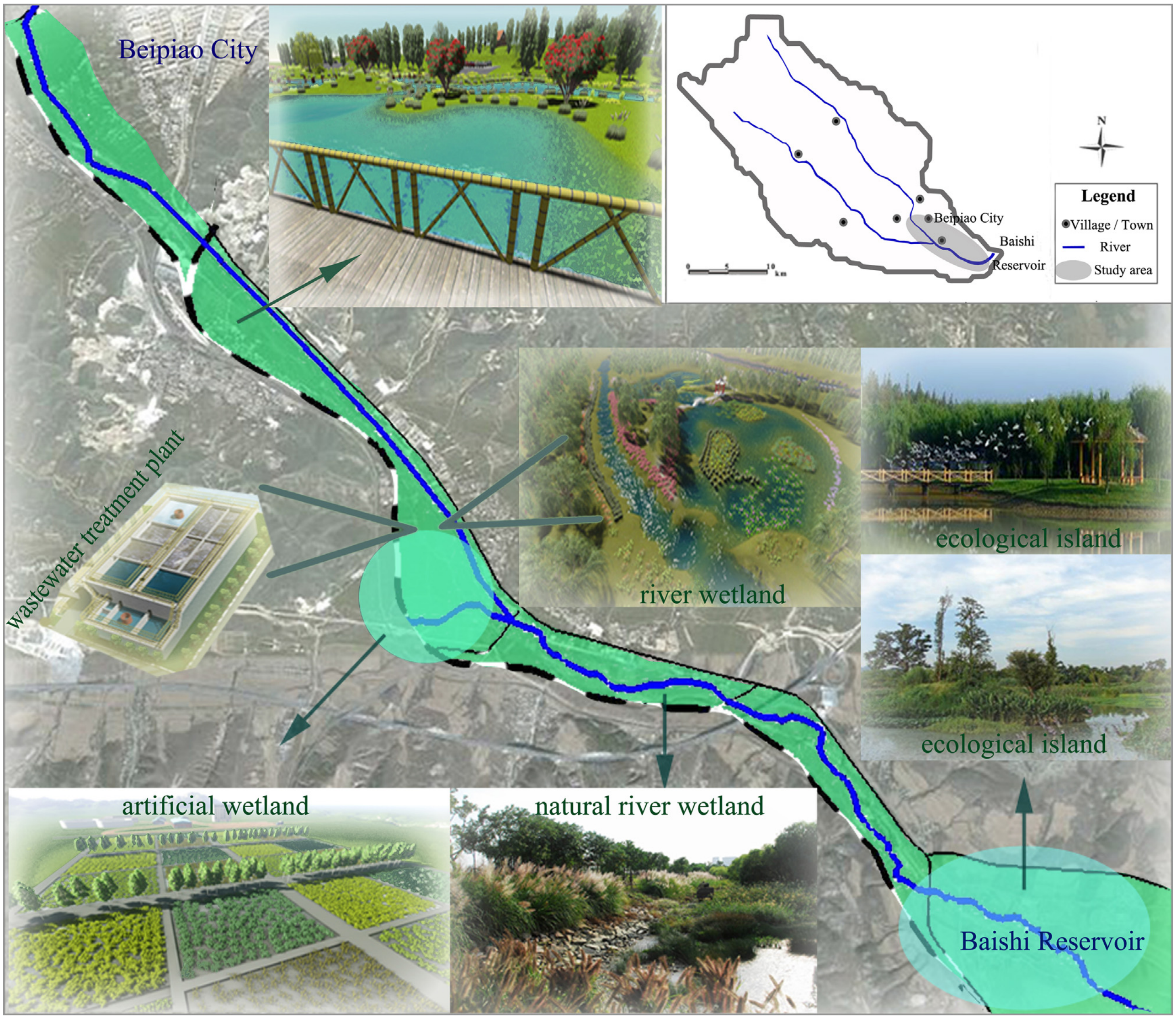

Fig. 3. Restoration layout of the Liangshui River.

of 10 km covering an area of 200,000 m^2, is designed to prevent and control soil erosion from flushing, retain and transform nutrients from nearby agriculture, purify and control polluted water of the river. Eventually, it is successful in handling floods, adjusting microclimate, maintaining biodiversity and keeping integrity of river ecosystem.

3.3.2. *Natural river wetland*

Considering the shallow depth and narrow water surface in some reaches, the construction of ecological wetland stretching across 250,000 m^2 is proposed, including point bar, channel bar and depression. The essential engineering measures of ecological submerged dam, diversion channel, down-flow weir, and proper biological measures of hydrophyte and mesophyte are effective to get rid of water pollution for further purifying water quality and improving ecological environment.

3.3.3. *Artificial wetland*

Because of low investing, low running costs, efficient wastewater treatment and easy maintenance, the constructed wetland system has been paid more attention. An artificial wetland system is designed, following the wastewater treatment plant of Beipiao City, to treat sewage and reclaimed water for further reuse. The artificial wetland is located at the right bank of Liangshui River, with an effective area of 10,080 m^2, containing eight treatment units. The water discharging capacity of constructed wetland is 20,000 m^3 per day based on the horizontal subsurface flow. After the processing, the main pollutant discharge target achieves the Grade III.

3.3.4. *Ecological islands*

Eco-islands have multiple functions including purifying water quality, providing bio-available habitat, improving the landscape and absorbing wave. Based on this, taking use of the dominant position of Baishi Reservoir area, three eco-islands are designed in the estuary of reservoir to control its inflow quality from Liangshui River. Eco-islands project will be an ecological filter strip for water conservation, environment optimization and landscaping.

A diagram of the restoration layout for Liangshui River ecosystem is shown in Fig. 3.

4. Conclusion

Disturbances on river ecosystems have raised wide concerns over the past few decades, and expectations of ecologically sustainable river utilization have been increased accordingly. The water resources development and water conservancy project has neglected the importance of organisms and water for the ecosystem, overlooked sustainability of the natural habitat in the system, broken its intrinsic balance and caused structural damage of integrity and stability.

The relationship between structure and function is a dialectical unity based on practice. Structure is the foundation of function, and function has a reverse influence on structure. The both are essential and complement each other to restrict and impact the sustainable development of river resources. Restoration of rivers must be started with evaluating the structure and function of the ecosystem. In this paper, a mathematical method for comprehensively assessing the structure and function of river ecosystem is developed based on the two-dimensional logical principle by Set Pair Analysis and Quadrant Method. The result shows that the study river ecosystem is defective in structure and sub-healthy in function.

A healthy river ecosystem means a pattern of sustainable development that aims to meet human reasonable needs based on the maintaining and preserving itself not only at present, but also for the future (Wen et al., 2007). In this pattern, it plays a key role in averting or reducing regional crises of rivers, functioning in service, culture and landscape security, and creating the maximal benefit of river resource in society, economy and environment fields. Based on the quantitative assessment of the structure and function of Liangshui River, engineering measures and primary technology for ecological restoration of the river are preferentially proposed. In addition, maintaining the integrity of river ecosystem and restoring it to a healthy status also needs non-engineering measures, including promoting the clean production in industry, strengthening the control of nonpoint source pollution in agriculture, enhancing the environmental legal enforcement, implementing strict water resource management.

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