Research and application of ecological river courses restoration technology

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Abstract. In this paper, a practical method of ordered binary comparison determined by weight vector is proposed, as based on correlative concepts of the dualistic relative comparative method in fuzzy mathematics. By taking advantage of the proposed method, subordinated degree of evaluation indicators can be defined, such as weightiness and the degree of importance of ecological restoration of river courses, and a mathematical model can be established. The proposed mathematical model is clear in its physical conception and offers convenient calculations, and provides a theoretical foundation for the ecological restoration of river courses. This paper employs "standard values" of the evaluation index system (EIS) of ecological river networks as derived by previous literature [1] as the theoretical basis for the ecological restoration river courses.

1. Introduction

In Dongying City, there are a total of thirty key river channels in addition to the Yellow River, and the basin area of each river exceeds 100 square kilometers. According to the size of basin area, the quantity of flood drainage flow and waterlogging drainage flow combine with the management and development of the river network in Dongying City; some rivers located in Dongying as part of the primary river course are listed. Every key river must satisfy the following requirements: its basin area must exceed 100 square kilometers, and its intra-regional length must be greater than 20 kilometers. Numerous EIS studies of the key ecological river network in Dongying City have been conducted based on this simulation [1].

Based on survey data and analysis of the current natural hydrographic network and the character of the ditch network, it was found that the hydrological integrity, chemical integrity, structural integrity, biological integrity and service integrity were unable to meet the requirements of an ecological river network. For this reason, previous literature [1] proposed the fundamental principle of constructing the ecological river network indicator system for Dongying City, and provided an EIS of ecological river courses and "standard values". Whereas the ecological river courses are described by numerous indicators, each indicator has unique impact on the ecological river courses, and varies in importance in regard to the repair of ecological river courses.

Kernal technologies involved in the restoration of ecological river courses includes description of impact, the development of repair strategies according to the importance of indicators, and methods for the application of standard indicator values as derived from previous literature [2].

In addition, many previous studies [1-5] demonstrate the application of the index system.
2. Weight vector of the ecological river course index system

In order to identify key points in the restoration of ecological river courses, the importance (weight) of each indicator reported in previous literature [1] must be determined. This paper refers to the method of ordered binary comparison in fuzzy mathematics, and proposes the practical method of ordered binary comparison driven by the weight vector.

A certain river course has two evaluation indicators: flood prevention ability and flood draining ability. To determine their relative importance, consider that flood prevention ability (identified as $x_1$) is more important than flood draining ability (identified as $x_2$), for fuzzy concept importance of B, the membership degree of this river course’s flood prevention ability which belongs to the "importance" is larger than that of the flood draining ability, from the fuzzy set point of view, as follows:

$$\mu_B(x_1) > \mu_B(x_2)$$

That is the concept of binary comparison.

Previous studies have detailed the theoretical demonstration of ordered binary comparison determined by weight vectors [6-10]. This paper details the concrete steps to determine the practical weight vectors of the evaluation index.

- Step 1: The weight (i.e., importance) of m evaluation indicators requires serious consideration. The number of the most important indicator is set to 1, and so on.

- Step 2: According to the features of the metric matrix (1) which reflect the importance of an ordered binary comparison, the values of the first row elements in the matrix (1) have been carefully constructed.

$$\mu = \begin{bmatrix} \mu_{11} & \mu_{12} & \cdots & \mu_{1m} \\ \mu_{21} & \mu_{22} & \cdots & \mu_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ \mu_{m1} & \mu_{m2} & \cdots & \mu_{mm} \end{bmatrix} = (\mu_{ij})$$ (1)

The values of the elements should satisfy the following conditions:

$$\begin{cases} 0 \leq \mu_{ij} \leq 1 & i \neq j \\
\mu_{ij} = 0.5 & i = j \\
\mu_{ij} + \mu_{ji} = 1 \\
\text{if } \mu_{kl} \leq \mu_{kg} , \mu_{kg} \geq \mu_{gl} \end{cases}$$ (2)

That is, the “importance” of binary comparisons between evaluation indicator 1 and evaluation indicator 2 must be specified, as well as the importance of comparisons between evaluation indicators 1 and evaluation indicator 3, …, between evaluation indicators 1 and evaluation indicator m, as follows: $\mu_{12}, \mu_{13}, \cdots, \mu_{1m}$, and there is a such condition: $0.5 < \mu_{12} < \mu_{13} < \cdots < \mu_{1m}$. Then, according to the condition $\mu_{ij} + \mu_{ji} = 1$ in Equation (2), the values of the elements in the first column of matrix (1) can be determined.

- Step 3: Based on the values of the indicators in the first row and the first column in matrix (1), the values of the elements in the first column of matrix (3) can be determined.
Formula (4) is deduced from the values of the elements in the first column of matrix (3).

\[
\alpha = \begin{bmatrix}
1 & \mu_{12} / \mu_{21} & \ldots & \mu_{1m} / \mu_{m1} \\
\mu_{21} / \mu_{12} & 1 & \ldots & \mu_{2m} / \mu_{m2} \\
\ldots & \ldots & \ldots & \ldots \\
\mu_{1m} / \mu_{m1} & \mu_{m2} / \mu_{2m} & \ldots & 1
\end{bmatrix}
\]  

(3)

The values of the elements should satisfy the following conditions:

\[0.5 < \mu_{12} < \mu_{13} < \cdots < \mu_{1m}\]

(4)

After normalizing formula (4), the weight vectors of m evaluation indicators is obtained.

In order to obtain the weight vectors of m evaluation indicators that conform to actual situations, the following strategies have been adopted in the current paper.

Relevant experts and leaders are invited to take an active part in certain organized activities; a well-designed questionnaire is employed. After careful consideration, the experts and leaders determine the "importance" of m evaluation factors according to a unified format, and determine the "importance" measurement value of binary comparisons based on the sorting result:\n
\[\mu_{12}, \mu_{13}, \cdots, \mu_{1m}\]

and a condition exists so that:

\[0.5 < \mu_{12} < \mu_{13} < \cdots < \mu_{1m}\]

After transferring the related data into Formula (4) and normalizing the data, each expert provides their determined weight vectors of m evaluation indicators. Then, the average value of each evaluation indicator is employed as the weight vector for further calculation.

Since each expert may consider a problem from individual aspect, this method is not the same as determining the "importance" of m evaluation indicators, so it cannot be based on the same number of evaluation indicators to determine the average value.

The construction of ecological river courses will depend on the weight values of the evaluation indicators. Greater values for evaluation indicators indicate more important functions, and greater impact on the ecological performance of a river course.

3. Degree of importance of river courses ecological restoration index system

If the value of a certain indicator is identical to or near its standard value under current conditions, though this indicator may be of great importance to the ecology of the river course, and the indicator weight may be very high, the priority harness of this river course is not encouraged.

In order to prioritize the implementation of river course ecological restoration and to highlight the significant values of the important indicators, the proposed method for determining the degree of importance of the river ecological management index system is provided under current conditions.

Suppose that the present quantitative value of a river ecological evaluation indicator is \(x_i\), and its standard value is \(S_i\). Then the degree of importance of ecological management is defined as follows:

\[W_i = \frac{|x_i - S_i|}{S_i}\]

(6)

The significance of each element is described as follows:

\(W_i\): The weight of the i-th indicator;
According to the importance of ecological management, the sequence of ecological and river course restoration is determined. The feature function is used to describe the descriptive indicators (such as slope shape, bank structure, embankment type, etc). The characteristic function of subset $A$ of the domain $U$ is expressed as follows:

$$
\chi_A(u) = \begin{cases} 
1 & u \in A \\
0 & u \notin A 
\end{cases}
$$

(7)

For example, suppose that subset $A$ represents the slope shape. When the slope shape of a river course belongs to the standard value of subset $A$, the value is equal to 1 and the rest of the values are equal to zero. Therefore, in the ecological river network EIS, for the current observed values $\bar{X} = (x_1, x_2, \ldots, x_n)$ and the standard values $\bar{S} = (s_1, s_2, \ldots, s_n)$, the degree of importance of each current monitoring indicator of ecological management can be calculated according to Formula 2.1 and Formula 2.2. The degree of importance will be an important basis for ecological restoration and restoration.

4. Case study

4.1. The ecological status of Yihong River

Yihong River derives its origin from Sheng Tuo Zhen Cui Jia, west of Kenli County, and runs south-east before, turning into the Guangli River and finally flowing into the Zhimai River. The length of the Yihong River is 48km, including a valley area of 312 square kilometers.

Under current conditions, its river slope is 1/7000-1/10000, water depth is between 1 and 2.5 meters, and the bottom elevation ranges from 5.4m to -1.0m. Its slope is approximately 1:3, and the maximum flow drainage is 110m$^3$/s. According to the two measured results from 2014, its water quality is shown in table 1.

| Base information | Field number of the sample points |
|------------------|----------------------------------|
| Sample point site| Spillway Q-1                      |
|                  | S231bridge(XiSi Road, HuangHe Road) |
|                  | Spillway Q-2                      |
|                  | DongBa Road Yihong River bridge   |
| Longitude        | NL: 37° 34´ 20"                  |
| Latitude         | EL: 37° 28´ 26"                  |
| Longitude        | NL: 118° 32´ 55"                 |
| Latitude         | EL: 118° 45´ 20"                 |

In the above table, two sample points are employed. The field number of one sample point is Spillway Q-1, and the other sample point is assigned the number Spillway Q-2. The basic information recorded at the two sample points is shown in table 2.

| Time (Year.Month) | Field number | Inspection result | Surface water class |
|-------------------|--------------|-------------------|---------------------|
|                   |              | NH4+ -N | CODcr |                     |
| 2014.08           | Spillway Q-1 | <0.05    | 107.30 | Poor V               |
|                   | Spillway Q-2 | 13.94    | 379.60 | Poor V               |
| 2014.10           | Spillway Q-1 | 0.28     | 100.39 | Poor V               |
Spillway Q-2   16.27   162.98   Poor ∨

Note: NL is the abbreviation of Northern latitude. EL is the abbreviation of east longitude.

The Delphi method is used to conduct research using "Back-to-Back" communication to consult with five local experts and seven community residents. After two rounds of consultation, the expert opinions and suggestions tend to conclude that the "Yihong River landscape coordination degree is very poor". In regard to the ecological environment of this river course, there is a great gap between the demands of the country people and local residents. Simultaneously, the environmental protection consciousness of local residents is not strong, and the emission dissatisfaction phenomenon of enterprises is a common occurrence. Based on the analysis of the overall ecological functions of the Yihong River, the primary task of the river’s ecological restoration is exceptionally arduous, and the goal of becoming an ecological river course has not been completely achieved.

4.2. The ecological EIS of Yihong River

According to actual investigation and the consultation of local experts and residents, there are 16 primary indicators in the ecological EIS of the Yihong River. Based on the methods for determining the weight vector of the indicators used in this paper, the weight of the evaluation indicators are shown in Table 3.

Table 3. The weight table of the evaluation indicators.

| Criterion layer | Primary evaluation indicators | Secondary evaluation indicators |
|-----------------|-------------------------------|---------------------------------|
| Nice natural functions (0.5) | 1. Storage of surface water (0.2) | 1. Flood control capacity (0.07) |
|                  | 2. Water quality (0.2)         | 2. Drainage capacity (0.07)     |
|                  | 3. Soil and water conservation (0.15) | 3. Ecological water requirement (0.06) |
|                  | 4. Corridor value (0.15)       | 4. COD (0.1)                    |
| Sustainable social and economic functions (0.5) | 5. NH3-N (0.1) | 5. NH3-N (0.1) |
|                  | 1. Sustainable use of surface water resources (0.16) | 6. Vegetation coverage (0.05) |
|                  | 2. Cultural leisure (0.7)      | 7. Slope shape (0.02)           |
|                  | 3. Environmental health (0.7)   | 8. Bank structure (0.05)         |
|                  |                               | 9. Embankment type (0.03)       |
|                  |                               | 10. Biodiversity corridors (0.08) |
|                  |                               | 11. Riparian vegetation zone (0.07) |
|                  |                               | 12. Rate of surface water resources development and utilization (0.16) |
|                  |                               | 13. Landscape coordination degree (0.04) |
|                  |                               | 14. Life satisfaction degree (0.03) |
|                  |                               | 15. Environmental protection consciousness (0.04) |
|                  |                               | 16. Health condition (0.03)     |
4.3. The ecological restoration of Yihong River

According to the standard value of ecological river network evaluation indicators in Hekou District [1] as combined with current ecological conditions of the Yihong River, the degree of importance of each current monitoring indicator of ecological management can be calculated according to Formula 2.1 and Formula 2.2. The degree of importance will be an important basis for ecological restoration and restoration.

Due to data limitations and based on the weight table of the evaluation indicators presented in Table 3, the present research provides the optimal order of current ecological restoration for the Yihong River, and proposes a plan for its ecological construction.

4.3.1. Flood control capacity and flood drainage ability. The flood control capacity and the flood drainage capacity of each section must not be less than a given value, according to previous literature [1].

4.3.2. Ecological water requirement. Because Yihong River passes through the county and in consideration of expert advice, the ecological water requirement of the Yihong River should increase by 10% based on a given value in previous literature [1].

4.3.3. Water quality. Considering the actual social economic development, the primary task is to achieve the following goals: COD≤35, NH3-N≤1.8, so as to achieve a water quality standard level IV or V. The long-term task is to achieve the following goals: COD≤30, NH3-N≤1.5, so as to achieve a water quality standard level III or IV.

4.3.4. Vegetation coverage ratio. According to the present conditions of Yihong River, the vegetation coverage rate is greater than 50%, and the long-term vegetation coverage rate is greater than 70%.

4.3.5. The slope shape, the bank structure and the embankment type. In the county town, the river slope shape should be a convex structure, and should use ecological slope protection measures so as to eventually become the natural revetment. For other river sections, step-by-step methods are adopted to reduce and eliminate the straight wall. During implementation, the following provisions should be observed.

- The distribution of the shoreline in the ecological protection area should ensure that the ecological shoreline ratio is not less than 80% and the production shoreline ratio is not greater than 5%.
- The distribution of the shoreline in scenic areas should ensure that the ecological shoreline ratio (according to the level of the scenic area) is not less than 30-50%, and that the production shoreline is not greater than 5-10%.
- As much as possible, the shorelines in the county should be living shorelines.
- The river slope is less than 1:3.

4.3.6. Biological diversity. A short-term goal is the realization of biological diversity greater than 0.5. A long-term goal is the realization of biological diversity greater than 0.7.

4.3.7. Bank vegetation belt. The bank vegetation belts within 20 meters on both sides of the Yihong River must be realized. Long-term goals include implementing bank vegetation belts within 30 meters on both sides of the Yihong River.

4.3.8. Development and utilization ratio of surface water resources. The rate of surface water resource development and utilization should be less than 60%.
4.3.9. \textit{Landscape coordination degree and life satisfaction degree.} Further expansion of the biological treatment measures in the river course must be achieved so that the river becomes a micro-sewage treatment site which will degrade some of the water pollutants and ensure water quality. The water body will achieve twists, turns and variety, in accordance with natural ecological changes, so that the value of ornamental scenery is greatly improved.

Local experts and residents are invited to participate in survey activities and sensory evaluation activities to achieve the following long-term goals: improved harmony between the Yihong River and the surrounding environment, and life satisfaction of local people that exceeds 90%.

4.3.10. \textit{Environmental protection consciousness and health condition.} Higher percentages of environmental consciousness indicate stronger environmental protection consciousness of local residents. Higher percentages of health condition indicates greater health improvement to local residents. The ecosystem of the regional river course is an important symbol of this region, and is likely to indicate whether the residents are happy and comfortable.

With the help of ecological construction to the Yihong River, the local residents will have good health and strong environmental awareness. The ultimate goal is that people with environmental protection consciousness exceed 90%, and those with good health exceed 95% of the population.

5. Conclusion

This paper provides a comparison to previously reported literature [1]. The "standard values" of the EIS of the ecological river network presented in previous literature [1] are used as the theoretical basis for ecological river network restoration.

The ecological features of a river course are described by numerous indicators, and are restricted to the economy, industry and downstream conditions. It is difficult to meet the standard values of an ecological river course perfectly. The ecological restoration process of rivers is gradual in practice, and greater importance placed on any particular indicator should be assigned priority in processing.

A practical method of ordered binary comparison determined by weight vectors is proposed, based on correlative concepts of the dualistic relative comparative method in fuzzy mathematics. By taking advantage of the practical method, the subordinated degree of evaluation indicators (i.e., weights) can be established, and the degree of importance of the river course in ecological management can be determined, as well as its mathematical model. The proposed mathematical model provides clear physical implications and convenient calculations, and provides a theoretical foundation for the determination of the ecological restoration order of river courses.

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