
Methodology Article

Research of Urban River Health Assessment Model

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Abstract: Urban river health is the important symbol of the sustaining development of a city. Using the comprehensive index assessment method, some indicators were selected to characterize the main features and functions of urban river health to establish a comprehensive model for evaluating urban river health. These indicators included four aspects: landscape environment, natural features, environmental features and socioeconomic. Total of them are 22 indicators. And the evaluation criteria were ascertained. Projection pursuit and variable fuzzy theory method were used to determine the weight of the indicators and the comprehensive assessment model was also built. This thesis discussed the issues of the urban river health situation of Jialu river, an urban river in Zhengzhou city. The evaluation results (0.23, 0.327, 0.245, 0.198) show that the Jialu river is in sub healthy state. Based on the health assessment results of Jialu river and evaluation score of each indicator, the limiting factors were ascertained that affect the urban river health. The calculated results are consistent with the actual situation, which shows the practicability and rationality of the method. The assessment model can provide reference for urban rivers health.

Keywords: Urban River Health, Index System, Projection Pursuit Method, Variable Fuzzy Set Theory

1. Introduction

Urban rivers are originate from urban areas, some of which have a history of artificial excavation and evolution with characteristics of natural rivers and canals [1]. With the rapid expansion of urban area and the constant intervention of human activities, there have some serious problems in urban rivers such as consume a lot of water resource, decline in biodiversity, emit large amounts of pollutants, and so on. Urban river natural and economic functions have seriously decreased and social and economic sustainable development has restricted.

Human has realized the importance of urban river health and improved higher requirement about integrated functions of urban river. In 1990, the US Environmental Protection Agency (USEPA) started a series of environmental testing related to the evaluation plan which monitored and evaluated the status of rivers and lakes [2]. In recent years, the United Kingdom, Sweden, Australia and other countries conducted extensive research on urban river health, such as the British

River Habitat Survey (RHS) [3]. Meyer considered urban river health should combined with social systems and take into account factors about human welfare [4]. Vugteveen reckoned river health not only to consider the function and structure of ecosystem, but also included the social and human values [5]; Australia provided the Index of Stream Condition (ISC) to evaluate the river health [6].

China researched lately about the river health research, such as Tang Tao [7] started to research the river health in 2002. Then, Changjiang and Yellow Water Resources Committees began to research the river health [8, 9]. In recent years, China continued to strengthen the protection of urban river health, more and more organizations started to research the urban river health [10].

Urban river health was a typical nonlinear complex system and the assessment model which should take into account the fuzziness, randomness and hierarchy about the factors of urban river health. Therefore, this thesis provided the urban river health assessment model which adopted the projection pursuit method [11] and variable fuzzy sets theory [12]. Those methods were used to determine the weight of the indicators

and the comprehensive assessment model was also built. The paper took Jialu river of Zhengzhou City as an example to evaluate its health situation. Based on the health assessment results of Jialu river and evaluation score of each indicator, the limiting factors were ascertained that affect the urban river health. Therefore, the model can provide the reference and scientific strategy for the government to assess the urban river comprehensively.

2. Survey of Research Area

Zhengzhou, located in the northern China, has 124 rivers which include 11 big rivers in the city, such as the Yellow River's tributary Ku river, Jialu river, Suoxu river, and so on. The city has 12 reservoirs and main channel in the middle route of the water transfer project from south to north, Long lake which constituted the Zhengzhou City river system. However, there are many urgent problems in the city river health, such as: flood control standard was low, irrational of water pollution and water quality function degradation. This paper researched the Jialu river which was highlighted in bold

in the figure 1. Jialu river length is 118.3 km, the drainage area is 2750 km² and the average annual runoff is 299 million m³ in Zhengzhou [13]. It is the main drainage channel of Zhengzhou city.

3. Urban River Health Assessment Model

3.1. Assessment Index System

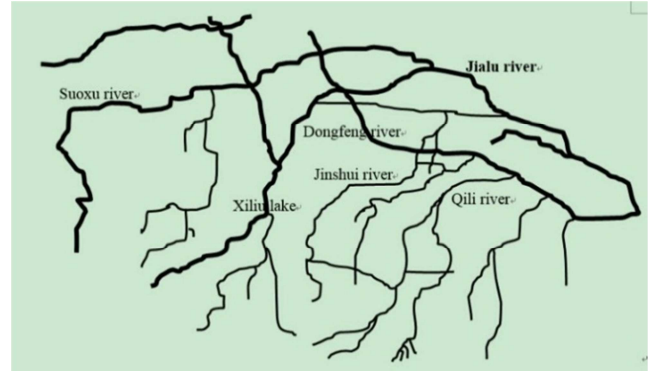


Fig. 1. Zhengzhou city river system.

Table 1. The health assessment system and indexes criterion of the urban river.

First level indexes	Second level indexes (%)	Level				
		I	II	III	IV	V
C ₁ : Landscape environment	D1: Riparian vegetation coverage ratio	>90	80-90	70-80	60-70	<50
	D2: River bed and bank stability	>90	80-90	70-80	50-70	<50
	D3: River ecological guarantee rate	>90	80-90	70-80	50-70	<50
	D4: Riparian wetland degradation rate	<30	30-40	40-50	50-70	>70
	D5: Natural degree of bank slope	>90	80-90	70-80	50-70	≤50
	D6: Public satisfaction	>95	80-95	65-80	50-65	<50
	D7: Waterfront building volume	>95	80-95	65-80	50-65	<50
	D8: River stop flow probability	<20	20-30	30-40	40-50	>50
C ₂ : Natural features	D9: Utilization ratio of water resources	<20	20-30	30-40	40-50	>50
	D10: Flow rate	>90	80-90	70-80	50-70	<50
	D11: Flood storage capacity	>90	80-90	70-80	50-70	<50
	D12: Water guarantee rate of ecological environment	>90	80-90	60-80	40-60	<40
	D13: Fish diversity index	>0.8	0.6-0.8	0.4-0.6	0.2-0.4	<0.2
	D14: River water quality comprehensive pollution index	<1	1-2	2-3	3-4	>4
C ₃ : Environmental features	D15: Rate of sewage treatment	>95	80-95	60-80	40-60	<40
	D16: COD attainment rate	>90	80-90	70-80	50-70	<50
	D17: Ammonia Nitrogen attainment rate	>90	80-90	70-80	50-70	<50
	D18: Dissolved oxygen concentration (mg/L)	>7.5	6.0-7.5	5.0-6.0	3.0-5.0	<3.0
C ₄ : Socioeconomic	D19: Water resources per capita/m ³	>3000	2000-3000	1000-2000	500-1000	<500
	D20: Water consumption per 10000 yuan of GDP/m ³	<100	100-150	150-250	250-350	>350
	D21: Flood control capacity attainment rate	>90	70-90	50-70	30-50	<30
	D22: Management level	>90	80-90	70-80	50-70	<50

Urban river health is a social-economic-natural complex function [14] which should be evaluated by the selected from multiple indexes. Urban river health based on the national, industry and local standards which included the *Indicators and criteria of healthy rivers* [15, 16], *Technical guidelines and standards for environmental impact assessment* [17], *Chinese Indicators, standards and methods of river health assessment (pilot work)* [18]. Urban river health system was divided into 4 first level indexes and 22 second level indexes based on theoretical analysis, engineering analogy method and expert consultation Table 1 showed the health assessment system and indexes criterion of the urban river.

3.2. Evaluation Standard

Urban river health involved many factors about the nature and society which based on the actual situation of urban rivers. According to the national standards and reference urban river health criteria, the thesis proposed the grade criteria based on the health level {I, II, III, IV, V}={health state, good tend, sub healthy state, unhealthy state, sick state}, corresponding to the allocation interval: [0, 1], (1, 2], (2, 3], (3, 4], (4, 5].

3.3. Projection Pursuit Method

Some traditional evaluation methods, such as analytic hierarchy process, fuzzy comprehensive evaluation and the gray theory influenced are based on the expert subjective factors. In this paper, projection pursuit and variable fuzzy set theory evaluated the indicators based on the objective data. The comprehensive method was suitable for the urban river health which involved multiple indexes and interdisciplinary study of factors. In this paper, projection pursuit [19] was a method that can be used in high dimension data analysis, both exploring analysis and certainty analysis. Projection pursuit can imitate experienced data analysis to make clustering and sorting by a new item which combine whole spread degree and partial agglomeration degree. Projection pursuit including the following steps:

3.3.1. Normalization of Sample

Suppose the sample collection of each index was $\{x'_{ij} | i = 1 \sim n, j = 1 \sim p\}$, x'_{ij} is the value of index j , n , p are the number of samples and indices respectively. For eliminating the dimension of the indices and normalizing the variety range of each index, unitary numerical value can be carried by the following formula:

For the index that more big more excellent:

$$x'_{ij} = \frac{x_{ij} - x_{\min}(j)}{x_{\max}(j) - x_{\min}(j)} \quad (1)$$

For the index that more small more excellent:

$$x'_{ij} = \frac{x_{\max}(j) - x_{ij}}{x_{\max}(j) - x_{\min}(j)} \quad (2)$$

where x_{ij} is the normalized sequence of eigenvalue index; $x_{\min}(j)$, $x_{\max}(j)$ are the maximum and the minimum values of the j index respectively;

3.3.2. Constructing Projection Index Function

Calculating the comprehensive projection eigenvalue function. The n dimension data can be integrated to the single dimension projection value y_i based on $b = \{b(1), b(2), \dots, b(n)\}$ in projection pursuit method:

$$y_i = \sum_{j=1}^n b_j x_{ij} \quad (3)$$

where y_i is the projection direction of projection values; b is a unite length vector.

When integrating projection index value it is demanded the scattering character of projection value y_i should be: partial projection points are as dense as possible, and it is better that agglomerate them to several points groups; but the projection points groups should be as dispersed as possible on the whole. So the projection index function can be expressed as:

$$T(b) = Q(b) \times D(b) \quad (4)$$

where $Q(b)$ is standard difference of projection value y_i ; $D(b)$ is the partial density of projection value, that is;

$$Q(b) = \sqrt{\sum_{i=1}^m (y_i - \bar{y}_b)^2 / (n-1)} \quad (5)$$

$$D(b) = \sum_{i=1}^m (R - r_{ik}) f(R - r_{ik}) \quad (6)$$

Where \bar{y}_b is the average value of sequence y_i ; R is the window radius of the partial density, it must be considered that the average number of projection points in the window not very few when the R value choosing to avoid the big average deviation of slippage, and to avoid it increase too much with n increasing. R can be determined according to experiment, it is commonly $0.1Q(b)$; r_{ik} is the distance of samples $r_{ik} = |y_i - y_k|$.

$f(t)$ is a unite rank spring function, it is 1 when $t \geq 0$ and 0 when $t < 0$.

3.3.3. Optimizing the Projection Index Function

When the sample collection of each index value was given, the projection index function $T(b)$ variety only with the projection direction b . Different projection direction reflects different character of data structure; the best projection direction is that can reveal some characteristic structure of high dimension data. so the best projection direction can be estimated through solving the maximizing of projection index function.

$$\max T(b) = Q(b) \times D(b) \quad (7)$$

3.3.4. Calculating Weight

Projection values obtained by above, it can calculate the weight of different evaluation indexes in evaluation system:

$$w_{ij} = y_{ij} / \sum_{i=1}^m y_i \quad (8)$$

Where w_{ij} is the weight for assessment indexes.

3.4. Variable Fuzzy Set Theory

Variable fuzzy set theory [20] was based on both probability theory and fuzzy theory and provides a new idea and approach for solving multi-objective decision-making problem among uncertain system. The procedure of variable fuzzy evaluation is described as follows:

3.4.1. Assessment of Values

Assume $X = (x_1, x_2, \dots, x_n)$ be a finite set of n feasible alternatives with m criteria to be considered, then the decision-making matrix can be denoted as $X = (x_{ij})_{m \times n}$, where x_{ij} is the value of the i th criterion for the j th alternative for all $i = 1, 2, \dots, m$ and $j = 1, 2, \dots, n$.

Assessed all values in X in the priority intervals between consecutive rankings and let the priority criterion matrix I_{ab} be:

$$I_{ab} = \begin{bmatrix} [a_{11}, b_{11}] & [a_{12}, b_{12}] & \cdots & [a_{1c}, b_{1c}] \\ [a_{21}, b_{21}] & [a_{22}, b_{22}] & \cdots & [a_{2c}, b_{2c}] \\ \vdots & \vdots & \vdots & \vdots \\ [a_{m1}, b_{m1}] & [a_{m2}, b_{m2}] & \cdots & [a_{mc}, b_{mc}] \end{bmatrix} = [a_{ih}, b_{ih}] \quad (9)$$

where a_{ih} and b_{ih} is the priority lower limit value and the priority upper limit value of the x_{ij} alternative belonging to the h th ranking for all $h = 1, 2, \dots, c$, respectively.

3.4.2. Interval Matrix

According the known priority interval, the certain interval can be determined and let certain interval matrix I_{cd} be

$$I_{cd} = \begin{bmatrix} [c_{11}, d_{11}] & [c_{12}, d_{12}] & \cdots & [c_{1c}, d_{1c}] \\ [c_{21}, d_{21}] & [c_{22}, d_{22}] & \cdots & [c_{2c}, d_{2c}] \\ \vdots & \vdots & \vdots & \vdots \\ [c_{m1}, d_{m1}] & [c_{m2}, d_{m2}] & \cdots & [c_{mc}, d_{mc}] \end{bmatrix} = [c_{ih}, d_{ih}] \quad (10)$$

where c_{ih} and d_{ih} is certain lower limit value and the certain upper limit value of the x_{ij} alternative belonging to the h th ranking, respectively, and which values are determined by lower limit value and upper limit value of neighboring interval in I_{ab} matrix.

3.4.3. Relative Membership

Let M is point value of the relative membership in priority intervals $[a_{ih}, b_{ih}]$ and let M be

$$M = \begin{bmatrix} M_{11} & M_{12} & \cdots & M_{1c} \\ M_{21} & M_{22} & \cdots & M_{2c} \\ \vdots & \vdots & \vdots & \vdots \\ M_{m1} & M_{m2} & \cdots & M_{mc} \end{bmatrix} = (M_{ih}) \quad (11)$$

M can be determined by midpoint value of intervals $[a_{ih}, b_{ih}]$.

3.4.4. Relative Membership Grade

Comparing x_{ij} and M_{ih} , if x_{ij} locates at left side of M_{ih} ($x_{ij} < M_{ih}$), its difference function is

$$\left. \begin{aligned} \mu_{-A}(x_{ij})_h &= 0.5 \left(1 + \frac{x_{ij} - a_{ih}}{M_{ih} - a_{ih}} \right); x_{ij} \in [a_{ih}, M_{ih}], \\ \mu_{-A}(x_{ij})_h &= 0.5 \left(1 - \frac{x_{ij} - a_{ih}}{M_{ih} - a_{ih}} \right); x_{ij} \in [c_{ih}, a_{ih}], \end{aligned} \right\} \quad (12)$$

And if x_{ij} locates at left side of M_{ih} ($x_{ij} < M_{ih}$), its difference function is

$$\left. \begin{aligned} \mu_{-A}(x_{ij})_h &= 0.5 \left(1 + \frac{x_{ij} - b_{ih}}{M_{ih} - b_{ih}} \right); x_{ij} \in [b_{ih}, M_{ih}], \\ \mu_{-A}(x_{ij})_h &= 0.5 \left(1 - \frac{x_{ij} - b_{ih}}{d_{ih} - b_{ih}} \right); x_{ij} \in [b_{ih}, d_{ih}], \end{aligned} \right\} \quad (13)$$

According equation (9)-(11) and normalization processing, the relative membership grade set can be obtained and let the set be

$$U = \left(\mu_{-A}(x_{ij})_h \right) \quad (14)$$

3.4.5. Eigenvalue Equation

The eigenvalue vector of air pollution risk rank can be calculated by rank eigenvalue equation and let rank eigenvalue equation be

$$H_k = (1, 2, \dots, c) \cdot U \quad (15)$$

Assess the level characteristic mean of evaluation objective:

$$\bar{H} = \sum_{k=1}^4 H_k / 4 \quad (16)$$

4. Data Sources

4.1. Data Analysis

The data of the Zhengzhou city river health assessment are mainly from the Zhengzhou City Water Resources Bulletin and Zhengzhou City Ecological River System Planning Report and River in Zhengzhou City Census [21, 22]. Other quantitative indicators of the status value was mainly related to consult expert advice which can conclude the value of status quo and data sources for each indicator on the basis of data collection.

4.2. Evaluation Results

Through the score of each first-class index and overall score

of the river (or samples of the river) through weighting of the Comprehensive Evaluation. Calculated values and evaluation results are presented in the Table 2.

Table 2. The health evaluation factor weight and reference sources of the evaluation indexes of the Jialu river.

Jialu River data	First level index	First level weight	Second level index	Second level weight	Reference source
82	C ₁	0.23	D1	0.129	Evaluation criteria of urban waterfront green space
76			D2	0.157	Expert advice
86			D3	0.131	Evaluation criteria of urban waterfront green space
41			D4	0.175	Evaluation criteria of urban waterfront green space
78			D5	0.169	Evaluation criteria of urban waterfront green space
71			D6	0.115	Expert advice
73			D7	0.124	Standard for river health assessment
15	C ₂	0.327	D8	0.201	Expert advice
18			D9	0.232	Expert advice
87			D10	0.146	Expert advice
79			D11	0.129	Expert advice
74			D12	0.138	Standard for river health assessment
0.63			D13	0.154	Evaluation criteria of urban waterfront green space
2.8			D14	0.272	Expert advice
67	C ₃	0.245	D15	0.184	Expert advice
72			D16	0.212	Surface water environmental quality standards
74			D17	0.178	Surface water environmental quality standards
5.3			D18	0.154	Surface water environmental quality standards
800			D19	0.243	Evaluation criteria of urban waterfront green space
270	C ₄	0.198	D20	0.268	Expert advice
46			D21	0.268	National standard for flood control
77			D22	0.221	Expert advice

From the Table 2, the comprehensive scores of the first level weight were:

$$(C_1 \ C_2 \ C_3 \ C_4) = (0.23 \ 0.327 \ 0.245 \ 0.198)$$

From the table data, the natural features was 0.327 which illustrated the natural ecological health was the basis of urban river. The scores of the landscape environment and environmental features were 0.23 and 0.245. The lowest weight of the first level index was the socioeconomic, 0.198 total of the first

levels were the 22 secondary indicators, the river water quality pollution was the highest weight, 0.272 which meant that the river was a high degree of industrial pollution. The other 12 additional indicators were below the average value which accounted to the total indicators, 54.5%. These showed that the overall health of the river system was instability based on the urban river health assessment results of Jialu river and evaluation score of each indicator.

Table 3. The grade distribution of health evaluation indexes of the Jialu river.

Evaluation method	First level index	Jialu river eigenvalues	Level
The method in this paper	C ₁	2.865	good tend to sub healthy state
	C ₂	2.568	good tend to sub healthy state
	C ₃	3.129	sub healthy tend to unhealthy state
	C ₄	3.527	sub healthy tend to unhealthy state
Set pair analysis method	Evaluation	3.058	III
	Evaluation	3.521	III
Fuzzy analysis method	Evaluation	3.127	III

From Table 3, the river health level was consistent to the results with the actual investigation by evaluation features at all levels. Results showed that the Jialu river is in sub healthy state, which environmental characteristics and social economy was in sub health tend to unhealthy state, the environment and natural landscape features was in good tend to sub healthy state. The set pair analysis method and the fuzzy analysis method calculated the urban river health to show that the results were the same to the paper method and correspond with the actual situation. Therefore, the urban river assessment

model can provide guideline for the health assessment of urban rivers.

5. Conclusion

Urban river health is a complicated system, which is affected by many factors. It is suit to use comprehensive index method to evaluate its health state. So it is important to establish a set of comprehensive index system which can reflect truly its health situation state. The combination of the

projection pursuit and the variable fuzzy theory can scientific and effectively to assess the urban river health. The evaluation results quantitatively reflect the state of the river and identify the influence urban river health factors. The model can guide the restoration of urban river health through quantify analysis. The assessment model of urban river health can expand urban river health research theory.

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