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River System Health Comprehensive Evaluation of Qilihe in Zhengzhou

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Abstract: In order to solve the problem of health status evaluation after Qilihe water system ecological management, put forward water system health definition, namely in a certain context, river system water quality is up to standard, the water surfer rate is suitable, the structure is perfect and reasonable, hydrologic situation is nature, the main functions are all normal, anti-interference performance is strong, ecological system is favorable, and river system is adapted to its environment and socio-economic characteristics, can maintain its sustainable development and its service society properly, can also act as a benchmark system for the river system and a particular state of health management goals. Based on the river system health definition, five first grade health indexes are selected namely hydrological condition, water environment condition, morphological structure and landscape condition, the condition of service function and water ecological status to construct the health evaluation index system of Qilihe river system which has 15 secondary indexes. The cloud evaluation model is used to evaluate river system health of Qilihe based on the analytic hierarchy process to determine weight of index. The result is showed that the evaluating value of Qilihe river system before the ecological management is 0.529, in the state of sub-health and the value after the ecological management is 0.645, in the state of health. Furthermore, the main influence factors of Qilihe river system health are the coastwise crowd's satisfaction, flood control capacity, the changing rate of annual average water, the water quality standard rate of water functional area, water resources control and dispatch ability and landscape diversity. It is suggested that Qilihe river system ecological management measures including the engineering technology and the gates and dam eco-dispatching are reasonable and effective.

Keywords: *eco-river system; cloud model; comprehensive evaluation; Qilihe*

1. Introduction

A variety of irrational human activities have led to increasingly prominent environmental and ecological problems in river systems, for example, aquatic organisms are declining and even endangered. These problems have attracted the broad attention of governments and scholars, hence giving birth to the idea of river health. Australia was the first to launch the National River Health Plan (HRHP) in 1993 [1,2], then research on river health evaluation and restoration was successively carried out in the US, Japan, Britain, Africa and China [3, 4]. The notion of river health is illustrated differently, and there mainly are three schools. In the view of Simpson et al. [5], river health means that river ecosystem supports and maintains major ecological processes and initial river conditions before disturbance is regarded as health. Karr [6] argued, using river value as a reference, as long as the current and future use value remained unimpaired and exerted no influences on the function of other connected systems, the ecosystem was healthy, namely whether the ecosystem was integrate or not made no difference. Fairweather [7] proposed that river heath should consider the public's expectations of river environment and river health cannot be defined without taking into account social, economic and political views. On the basis of the previous two opinions, Meyer [8] included ecological integrity and human value in river health. In his view, a healthy river ecosystem is not only to maintain ecosystem structure and function, but to involve human and social value. In China, there exists an increasingly visible interest in sever water problems, mainly health of the Yellow River, among experts and scholars. GAO Yongsheng [9] has proposed that river ecosystem health means that river ecosystem cannot only maintain integrity despite human interference, but sustain various services offered by human society. DONG Zheren has pointed out that river health, as a tool for river management assessment, is to research the evolution trend of a river and promote its sound development through management.

The Australian Index of Stream Conditions (ISC) establishes an index system based on river hydrology, river morphology, riparian zone conditions, water quality and aquatic organisms. Experts and scholars in China have actively explored river health and yielded fruitful results. ZHANG Kegang proposed 14 evaluation indexes of river health based on river hydrology, physical structure features, riparian zone conditions, water pollution and aquatic organisms. WANG Lin [13] added such social indicators as public attitudes, river management and flood control safety on the basis of ISC method to establish an overall index system covering environment, hydrology, water conservancy, ecology, physical structure and social function. As a management tool, river health faces a key issue that is how to select a baseline state. LIU Xiaoyan [14] suggested that standards for river health are the balance or compromise between the interests of human and other living things during a period or in a part of the river, so river health is a relative notion and its standards are actually a social choice against different backgrounds. Compared with the single river structure, river system structure is more complex and has a much larger spatial and temporal scale. Consequently, in terms of river system health, there have been fewer research results which are obtained by using large-system dissembling and coordination strategy to divide summaries, without ideal integrity and effects.

To sum up, it is widely believed that river health is a tool for river construction and management evaluation. There have been fruitful research results concerning such aspects of river health as definition, connotation, evaluation standards and methods, laying a solid foundation for the evaluation of urban river system health. On the other hand, there have been fewer research results concerning health of an entire river system which is still at a groping stage, failing to meet the demands of ecological river system construction in urban areas. There is an urgent need for in-depth research and exploration. Based on the existing research results of river health, this paper illustrates a scientific and reasonable notion of river system health as follows: in a certain context, both river system and headwater have a good quality, appropriate surface rate, complete and accessible structure, likely hydrological regime, huge river basins, complete main function, good capacity of resisting disturbance and favorable ecosystem. In addition, they should be in line with the local socio-economic characteristics to maintain sustainable development and reasonably serve the community. All these are to meet the basic standards of river system and manage the targeted specific state.

Controlled by various factors, the comprehensive evaluation of river health is not only multi-level and random but fuzzy and intricate, so there is a complex relationship between evaluation indexes and even evaluation results of each single index may be inconsistent. As a result, it is difficult to make river system health evaluation gratifying. In this paper, cloud theory is introduced to establish a cloud model for making a comprehensive evaluation of the Qili river system health by integrating fuzziness and randomness of evaluation grades.

2. Overview of the Qili River System

The Qili River originates in the east of Chujianao Village, Xiaoqiao Township, Xinzheng County and flows north to the Dongfeng Channel. With a length of 47.2 km, it covers a drainage area of 741.0 km2. The upper reaches contain the ShiQili River and the Shibali River respectively. The source of the ShiQili River is in Banpo Village, Guodian Township, Xinzheng City, with a total watercourse length of 23.7km and a drainage area of 90.63km2. The watercourse length in Zhengzhou is 12.7 km. Such reservoirs as Post-Taipinggou, Luodong, and Linjindian are established along the river, and there are many irrigation stations. The source of the Shibalihe River is in Mengzhuangnangou Village, Xiaoqiao Township, Xinzheng City, with a total watercourse length of 24.8 km and a drainage area of 112.3km2. The two rivers join together in the south of Baizhuang Village, Guancheng District and then flows into the Qili River. The watercourse length in Zhengzhou is 12.7 km 10.5 km [15]. Additionally, the Chaohe River and the Dongfeng Channel joins the Qili River on the middle and lower reaches of main watercourse. The Dongfeng Chanel is also joined by the Jinshui River and Ronger River, both of which flows through Laocheng District. Map 1 shows the Qili River System.

With the advancement of urbanization drive in Zhengzhou City, the Qili River System has been invaded and contaminated, giving rise to a variety of serious problems, including poor connectivity, inadequate carrying capacity of water resources and environment, flood drainage difficulty, frequent urban floods and increased water security risks. By 2005, the Qili River System had an offensive smell of sewage in the non-flood season, while the flood season saw an overflow of sewage after a rainstorm. Water quality of a river section was above the V-class water standard, failing to meet the standard water quality required by water function area and eco-system. A series of problems arouse such as serious water pollution, destroyed ecosystem and loss of basic functions.

As the idea of river health has been deeply rooted in the hearts of people, leaders of Zhengzhou municipal committee and government showed great foresight in 2006 and clearly proposed that we should govern Zhengzhou and its surrounding river systems at a high starting point and to a high standard to realize the goals of “water connectivity, clear water and beautiful scenery” and create a beautiful water city in Northern China. The Qili River System is an important part of ecological water system in Zhengzhou City, the plan for which was completed in 2007. It was greatly improved through such river system management as ecological improvement and regulation during the period of 2008-2012, basically realizing the goals of water connectivity and clear water. In particular, Zhengzhou Water Supplies Bureau has managed the Qili River System health through ecological projects – including water surface expansion, river system connectivity and ecological restoration of riverbank – as well as advanced ecological restoration technologies and ecological regulation measures of gate dams.

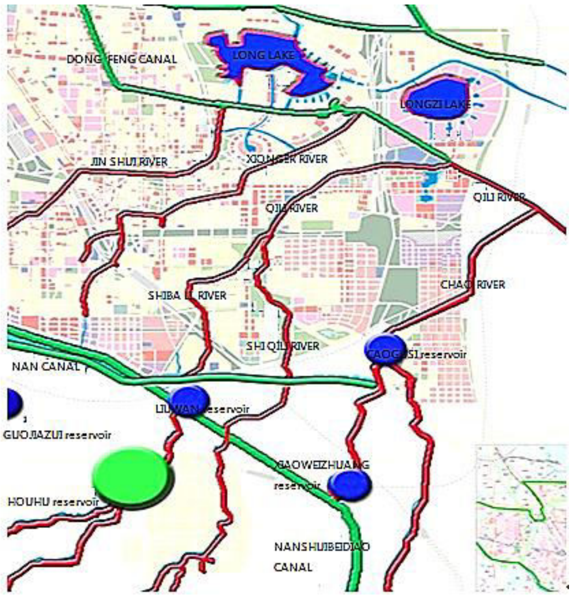

Fig. 1: *The Qili River basin*

3. Evaluation model based on cloud theory

Let factor set be $U=\{u_1,u_2,\cdots,u_n\}$, evaluation set be $V=\{v_1,v_2,\cdots,v_m\}$ and factor weight set be $W=\{w_1,w_2,\cdots,w_n\}$, and all of them are finite sets. Numerical characteristics of the qualitative concept expressed by the cloud model are determined based on the single-factor evaluation criterion, namely (Ex,En,He). Let the upper and lower boundary value of grade $j, j=1,2,\cdots,m$ corresponding to factor $\mathrm{i}, \mathrm{i}=1,2,\cdots,\mathrm{n}$ is $x^1_{i,j}, x^2_{i,j}$ respectively, then the grade j of factor i can be expressed by the following cloud model

$$Ex_{i,j}=(x^1_{i,j}+x^2_{i,j})/2 \tag{1}$$

Where, boundary value is the limit of two opposite grades and it can be seen that membership of two adjacent grades is equal [16], which can be written as:

$$exp\left[-\frac{\left(x^1_{i,j}-\mathrm{x}^2_{i,j}\right)^2}{8(En_{i,j})^2}\right]\approx 0.5$$

$$En_{i,j}=\frac{x^1_{i,j}-x^2_{i,j}}{2.355} \tag{2}$$

Super entropy $He_{i,j}$ represents uncertainty measure of entropy [17] which indicates the cohesiveness of cloud droplets. A larger entropy value means a thicker cloud, and vice versa. The value can be determined through experience and experiments on the basis of $En_{i,j}$.

After determining the numerical characteristics of cloud model for each grade, a cloud generator is utilized to calculate and derive the membership matrix R based on each index of an evaluation object.

$$R=\begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \cdots & \cdots & \cdots & \cdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{bmatrix}$$

The membership matrix derived from cloud model is random, which shows the correlation between U and V. As a fuzzy subset of U, weigh set W can be employed together with R to make a fuzzy transformation to derive the fuzzy subset B of V [17].

$$B=W\otimes R \tag{3}$$

To make evaluation more reasonable and deal with the condition when maximum membership principle fails to prevail in terms of equal membership of grades, this paper uses the variable fuzzy recognition model to calculate evaluation grades, and the formula can be given as:

$$u_j^{'}=1/[1+(\frac{d_{jg}}{d_{jb}})^a] \tag{4}$$

Where, $d_{jg}=[\sum_{i=1}^{n}[w_i(1-r_{ij})]^p]^{1/p}$ (5)

$$d_{jb}=[\sum_{i=1}^{n}[w_i(r_{ij})]^p]^{1/p} \tag{6}$$

Where, $u_j^{'}$ is the overall relative membership of sample concerning grade j without normalization; p is the distance parameter and in this paper $p=2$; and a is the optimization guideline parameter which is nonnegative number as stipulated in literature [17]. Here $a=1$, so that membership can really mirror the data information. The grade of project to be evaluated can be calculated as:

$$j^*=\frac{\sum_{j=1}^{m} j\cdot u_j^{'}}{\sum_{j=1}^{m} u_j^{'}} \tag{7}$$

Where, j^* is an evaluation grade.

4. Comprehensive evaluation of the Qili River System health

4.1. Comprehensive evaluation index system for the Qili River System health

Based on analyzing the related research results [15] and the definition of river system health, this paper clearly illustrates that the comprehensive evaluation index system for urban river system health should reflect hydrologic conditions, water environment, morphological structure and landscape, services and water ecological regime. Moreover, the overall health status and change trend of Qili River System should be indicated. Combining the realities of study area in Qlihe river system can acquire related information. Under the principles of combining systematisms and hierarchy, feasibility and operability, comparability and flexibility as well as continuity and dynamics, such methods as frequency statistics, theoretical analysis and expert consultation are used to establish an evaluation index system that can fully reflect the Qili River System health.

Table 1: *Comprehensive evaluation index system for the Qili River System health*

System	Subsystem	No.	Indexes
River ecosystem health Index (S)	Hydrological conditions ($s^{(1)}$)		Annual average flow change rate
			Relative drying-up days
			Ecological water demand guarantee rate
	Water environment conditions ($s^{(2)}$)		Standard water quality rate in water function area
			Soil and water loss proportion
			Self-purification rate of water body
	Morphological structure and landscape ($s^{(3)}$)		Stability of riverbed and river bank
			Vertical continuity (the number of gate dams per 10 kilometers)
			Horizontal and vertical connectivity
			Landscape diversity
	Services ($s^{(4)}$)		Satisfaction of people along the river bank
			Flood control capacity
			Regulation ability of water resources
	Water ecological regime ($s^{(5)}$)		Survival of aquatic organisms
			Biodiversity

In the index system, such qualitative indexes as stability of riverbed and river bank, horizontal and vertical connectivity, public satisfaction and flood control standards are quantified by grading (hundred-mark system) based on the survey of expert group, while other quantitative indexes are worked out based on corresponding quantified calculation methods shown in Table 2.

In light of historical data and relevant information collected from 2012-2013 [15], there are pre-improvement and post-improvement evaluation for the Qili River System health. Index value is filled in Table 3 based on calculations in Table 3 and expert grading. The source of the data about index is Zhengzhou Water Affairs Bureau.

Table 4 shows the grading standards for the Qili River System health evaluation, which are set on the basis of related research results and demonstration of expert group. Such ranges as 0~0.2, 0.2~0.4, 0.4~0.6, 0.6~0.8 and 0.8~1.0 are used to represent breakdown, pathos is, sub-health, health and excellent health respectively. In this paper, related historical data on relevant rivers, research results and national applicable standards are used for reference, and comparative analyses of various regions are made. Furthermore, on the basis of public participation, experts judge and define the grading standards for various subsystems, as shown in Table 5. Weight is determined by AHP.

Table 2: *Quantified calculation of the Qili River System health evaluation indexes*

Indexes	Quantified calculation
Annual average flow change rate	(Current annual average flow - Average flow over years) / Average flow over years ×100%
Relative drying-up days	(Current drying-up days – Historical drying-up days) /(365 - Historical drying-up days)×100%
Ecological water demand guarantee rate	Ecological water supply /Total ecological water demand ×100%
Standard water quality rate in water function area	Length of reach with standard water quality in water function area /Overall river length×100%
Soil and water loss proportion	Area of soil and water loss within the watershed /Total watershed area×100%
Self-purification rate of water body	Length of self-purification reach /Overall river length×100%
Vertical continuity	The number of gate dams per 10 kilometers

Regulation ability of water resources	Regulation flow /Total annual flow×100%
Landscape diversity	$s=-\sum_{i=1}^{N} p_i \ln p_i$ where P is the proportion of landscape i in total area and N represents total landscape types
Biodiversity	$D = s/\ln A$ where S is the total number of species in the community and A is unit area

Table 3: *Qili River System health evaluation value*

Index No.	Pre-improvement value (2005)	Average post-improvement value (2012-2013)
1	60%	20%
2	54%	5%
3	40%	85%
4	18%	70%
5	40%	8%
6	20%	75%
7	50	75
8	5	6
9	35	65
10	1.5	2.1
11	51	80
12	80	85
13	51%	81%
14	45	75
15	1.8	2.8

Table 4: *Grading standards for comprehensive evaluation of the Qili River System health*

Grades	Ecological significance
Grade Ⅰ Excellent health	The river system is basically in a primitive state without human disturbance. The river system is in health.
Grade Ⅱ Health	The river system is subject to some human disturbance which exerts no effects on the survival of aquatic organisms. The river system is basically healthy.
Grade III Sub-health	The river system is subject to human disturbance which greatly affects the survival and reproduction of aquatic organisms. The river system is in sub-health.
Grade Ⅳ Pathosis	The river system is severely destroyed as a result of human disturbance and ecosystem balance is on the verge of breakdown. The river system is in pathosis.
Grade Ⅴ Breakdown	Structure and function of the river system are completely destroyed and contaminants have lasting and accumulative pollution effects on aquatic organisms. The river system is in a state of breakdown.

Table 5: *Standard value of ecological evaluation indexes*

Subsystem	Evaluation index	Weight	Standard value				
			Grade Ⅰ	Grade Ⅱ	Grade III	Grade Ⅳ	Grade Ⅴ
S(1)	Annual average flow change rate (%)	0.080	≤5	15	30	40	≥40
	Relative drying-up days (%)	0.071	0	20	40	60	≥60
	Ecological water demand guarantee rate (%)	0.056	≥90	80	65	50	≤50
S(2)	Standard water quality rate in water function area (%)	0.081	≥80	60	40	20	≤20
	Soil and water loss proportion (%)	0.045	≤5	10	20	40	≥40
	Self-purification rate of water body (%)	0.062	≥80	60	40	20	≤20
S(3)	Stability of riverbed and river bank	0.061	Excellent ≥80	Good 60	Secondary40	Poor 30	Very poor
	Vertical continuity(number)	0.046	≤2	4	6	8	≥8
	Horizontal and vertical connectivity	0.027	≥80	60	40	20	≤20
	Landscape diversity	0.074	≥3	2	1.5	0.5	≤0.5
S(4)	Satisfaction of people along the river bank	0.100	≥90	75	50	20	≤20

	Flood control capacity	0.100	≥80	60	40	20	≤20
	Regulation ability of water resources (%)	0.078	≥90	80	60	30	≤30
S(5)	Survival of aquatic organisms	0.053	Excellent ≥80	Good 60	Secondar y40	Poor 30	Very poor≤30
	Biodiversity	0.066	≥4	3	2	1	≤1

4.2. Evaluation results and analyses

Based on the comprehensive evaluation index system and standards for the Qili River System health, a cloud model is used to calculate the value of various indexes before and after ecological improvement, as shown in Table 6.

Table 6: *Comparing comprehensive evaluation of the Qili River System health*

Different periods	Evaluation value	Evaluation result
Before ecological improvement(2005)	0.529	Sub-health
After ecological improvement(2012-2013)	0.645	Health

This paper introduces a cloud model to comprehensively evaluate the Qili River System health and calculates the pre-improvement and post-improvement evaluation value which is 0.529 and 0.645 respectively. That is to say, the Qili River System is in sub-health and close to pathos is before ecological improvement (2005), suggesting that ecosystem of the river system is subject to disturbance which greatly affects the survival and reproduction of aquatic organisms. After ecological improvement (2012-2013), the Qili River System is in health, which means that more human disturbance and services, together with further developed landscape system, exert no effects on the survival of aquatic organisms. But the evaluation value is not large due to the short time of ecological improvement and regulation.

5. Conclusions

(1) River system health is illustrated as follows: in a certain context, both river system and headwater have a good quality, appropriate surface rate, complete and accessible structure, likely hydrological regime, huge river basins, complete main function, good capacity of resisting disturbance and favorable ecosystem. In addition, they should be in line with the local socio-economic characteristics to maintain sustainable development and reasonably serve the community. All these are to meet the basic standards of river system and manage the targeted specific state.

(2) Since 2008, ecological improvement and ecological regulation of gate dams have turned the Qili River System from sub-health to health, demonstrating the reasonability and validity of ecological restoration projects in the Qili River System and ecological regulation measures for gate dams.

(3) Such indexes as public satisfaction, flood control capacity, annual average flow change rate, standard water quality rate in water function area, regulation ability of water resources and landscape diversity are major influencing factors, to which should be attached more importance in future management of the Qili River System health so as to accelerate its sound development.

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