Research on the Lake Health Evaluation based on Multi-Dimensional Index System Taking Dongshan Lake as an Example

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Abstract: With the development of economy and society, the production and life of human beings gradually have a negative impact on the water body of rivers and lakes. Restoring the health of rivers and lakes has gradually become an important task. River and lake health evaluation is an important basic work to strengthen the management and protection of rivers and lakes, and with the in-depth implementation of the River Chief System (RCS) and the Lake Chief System (LCS), it has attracted more and more attention. In this paper, focusing on the comprehensive management and protection of lakes, with the help of the multi-dimensional index system of lake health evaluation in the Evaluation Guidelines and Technical Guidelines, the Dongshan Lake in Guangzhou was taken as an example to study and determine the multi-dimensional health evaluation index system. Utilizing the index system, the health evaluation and overall health characteristics analyzation of Dongshan Lake were carried out, and the specific protection countermeasures and suggestions were given. This research has a certain reference value for the systematic health evaluation and protection of lakes.

1 INTRODUCTION

There are many lakes in China. According to statistics, there are 2,759 natural lakes larger than 1.0km[2] in the country, with a total area of 91019.63km[2] (Wang and Dou, 1998). Lake is one of the natural units in the natural ecosystem on which human beings depend for survival. As a unique resource, lakes play a huge social and economic role in water supply, flood control, aquaculture, tourism, shipping, maintaining ecological balance and environmental protection. With the increase of population and the development of industrial and agricultural production, the discharge of industrial wastewater and domestic sewage is increasing, and the lake ecosystem on which human beings depend is degraded, especially the problem of eutrophication, which has seriously threatened the sustainable development of social economy and human health (Pu et al., 2014). Therefore, studying the lake ecosystem, establishing a lake ecosystem health evaluation system and index thresholds, and ensuring the water demand of the lake ecological environment, not only can provide a comprehensive, authoritative and operational decision-making basis for the rational

allocation of water resources and lake management, but also be conducive to the sustainable management and rational utilization of the lake ecosystem, as well as the realization of ecological coordination of social and economic benefits (Steedman, 1994; Hu et al., 1998; Jones and Taylor, 1999; Ladhar, 2002) .

On January 12, 2012, the State Council issued the Opinions of the State Council on Implementing the Most Strict Water Resources Management System (Guofa [2012] No. 3), which proposed to promote the protection and restoration of aquatic ecosystems, to study the index system establishment of ecological water use and ecological evaluation of rivers and lakes, to regularly organize the health assessment of important rivers and lakes nationwide, and to establish and improve the water ecological compensation mechanism. On March 21, 2014, the Ministry of Water Resources issued the Guiding Opinions on Strengthening the Management of Rivers and Lakes (Shuijianguan [2014] No. 76), which proposed that by 2020, the river and lake health security system should be basically established, the river and lake management system and mechanism should be established and improved, and the efforts should be made to achieve no shrinkage of rivers and

lakes, no degradation of functions, and no ecological degradation.

In order to thoroughly implement the Opinions on the Full Implementation of the River Chief System (RCS) and the Guiding Opinions on the Implementation of the Lake Chief System (LCS) in Lakes by the General Office of the CPC Central Committee and the General Office of the State Council, guide all localities in carrying out river and lake health assessment work and promote RCS and LCS to be Famous, Realistic and Capable, the Department of River and Lake Management of the Ministry of Water Resources organized the Nanjing Institute of Hydraulic Research and other units to formulate the Guidelines for Health Evaluation of Rivers and Lakes (Trial) (hereinafter referred to as the Evaluation Guidelines) , so as to provide a scientific standard for testing the effectiveness of RCS and LCS in various regions in China (Liu et al., 1999).

River and lake health evaluation is an important content of river and lake management. It will provide an important basis for determining the health status of rivers and lakes, finding river and lake problems, analyzing pathogeny, and proposing governance countermeasures. It is an important basis for realizing river and lake system governance and long-term governance. This paper took the Dongshan Lake as an example, and conducted health evaluation on the lake according to relevant guidelines. On this basis, it analyzed and evaluated the problems of the Dongshan Lake from four aspects of health evaluation indices, studied and put forward a systematic restoration strategy for the lake to provide decision-making basis for realizing long-term governance and effective management of the lake.

2 MULTI-DIMENSIONAL HEALTH EVALUATION INDEX SYSTEM FOR LAKES

In August 2020, the River Directors Office of the Ministry of Water Resources issued the Evaluation Guidelines, pointing out that the health evaluation of rivers and lakes is an important content of river and lake management, and an important means to test the Famous and Real of RCS and LCS. The results of river and lake health assessment are an important reference for the river and lake directors to carry out the protection and management of rivers and lakes.

In May 2021, based on the Evaluation Guidelines, the Office of the Leading Group for the Comprehensive Implementation of the River Chief

System in Guangdong Province compiled the Guangdong Province 2021 River and Lake Health Evaluation Technical Guidelines (hereinafter referred to as the Technical Guidelines), which combined the characteristics of rivers and lakes in Guangdong Province and the actual situation of river and lake management, and condensed foreign and domestic research results and practical experience, was used to guide all localities to carry out river and lake health evaluation .

For lake health evaluation, the technical guidelines adopt a multi-dimensional health evaluation index system, in which 22 indices are involved in the evaluation of lakes from four criteria layers including "Basin" (i.e. lake physical structure), "Water" (i.e. lake water environment), Biology (i.e. lake water ecology), and social service functions (Table 1). All evaluation indices are divided into Required Indices and Optional Indices based on lake functions, index importance, difficulty in obtaining index data, etc. These indices can scientifically and comprehensively evaluate the performance of river and lake governance from the perspective of river and lake health.

Table 1: Lake health evaluation index system and survey sampling scope.

Criterion layer		Index layer	Index type	Survey or sampling monitoring scope	Specific location
"Basin"		Lake connectivity index	Optional indice	Evaluation Lake	River around the lake
		Lake area shrinkage ratio	Required indice	Evaluation Lake	Water area
		Natural conditions of shoreline	Required indice	Monitoring section	Lakeshore zone
		Degree of illegal development and utilization of water shoreline	Required indice	Evaluation Lake	Water area and lakeshore zone
"Water"	Volume	Satisfaction degree of minimum ecological water level	Required indice	Monitoring point	Water area
		Variation degree of inflow	Optional indice	Evaluation Lake	River around the lake
	Quality	Quality of water	Required indice	Monitoring point	Water area
		Lake nutritional status	Required indice	Monitoring point	Water area
		Sediment pollution status	Optional indice	Monitoring point	Water area
		Water self-purification capacity	Required indice	Monitoring point	Water area
Biology		Macrobenthic Invertebrate Biological Integrity Index	Optional indice	Monitoring point	Aquatic organism sampling area
		Fish retention index	Required indice	Evaluation Lake	Water area
		Water and bird conditions	Optional indice	Evaluation Lake	Water area and lakeshore zone
		Phytoplankton density	Required indice	Monitoring point	Water area
		Macrophyte coverage	Optional indice	Monitoring point	Nearshore zone
Social Service Functions		Flood control compliance rate	Optional indice	Evaluation Lake	Lakeshore zone
		Water supply guaranteed degree	Optional indice	Evaluation Lake	Water area
		Water quality compliance rate of lake centralized drinking water source	Optional indice	Evaluation Lake	Water area
		Shoreline utilization management index	Optional indice	Evaluation Lake	Lakeshore zone
		Comprehensive benefits of Green Road construction	Optional indice	Evaluation Lake	Lakeshore zone
		Water and soil conservation rate of watershed	Optional indice	Evaluation Lake	Catchment area
		Public satisfaction	Required indice	Evaluation Lake	Surrounding public

3 GENERAL SITUATION OF DONGSHAN LAKE AND DETERMINATION OF ITS HEALTH EVALUATION INDEX SYSTEM

3.1 General Situation of Dongshan Lake

The Dongshan Lake, built in 1958, is located to the east of the North approach bridge of Haiyin bridge, adjacent to the Pearl River in the south, connected to Zhudao hotel in the East and Guigang business district in the north. It is composed of the West Lake, the Nanpian Lake and the Dongpian Lake, and is one of the four largest artificial lakes in Guangzhou. Its main functions are rain and flood regulation and entertainment. The Dongshan Lake receives the water from the upstream of the Donghaochong River and the Xinhepu River in the north, and is connected with the Ersha River through two sluices (Sluice No. 6 and Sluice No. 8) in the south, with a total rainwater collection area of 4.48km^2. The normal water storage level of the lake area is 5.50m, the water surface area is 0.355km^2, the water storage capacity is 410,700 m3, the current regulated storage control water level is 6.80m, and the water storage capacity is 802,700 m3. The geographical location of Dongshan Lake is shown in Figure 1.

Figure 1: Schematic diagram of the location of the Dongshan Lake.

At present, the pollution interception of the Dongshan Lake has been basically completed, and the direct discharge pollution sources of industry, agriculture and catering industry have been basically eliminated. However, due to the impact of various factors such as flood discharge and drainage, sewage overflow, incoming water quality and surface runoff, the water quality of the Dongshan Lake fluctuates, which makes it difficult for the Dongshan Lake to maintain a stable monthly standard without the discharge of surrounding pollution sources. Due to insufficient exchange frequency with surrounding rivers, the low flow rate and the poor water dynamics, the water ecological environment of the Dongshan Lake needs to be improved.

3.2 Determination of the Multi-Dimensional Health Evaluation Index System of the Dongshan Lake

This paper refers to the Technical Guidelines to construct an index system for evaluating the health of the Dongshan Lake, as shown in Table 2. From the table it can be seen that there is a total of 18 evaluation indices among the four criterion layers of the Dongshan Lake health evaluation index system, including 10 required indices and 8 optional indices.

Table 2: Health evaluation index system of the Dongshan Lake.

Criterion layer		Index layer	Index type
"Basin"		Lake connectivity index	Optional index
		Lake area shrinkage ratio	Required index
		Natural conditions of shoreline	Required index
		Degree of illegal development and utilization of water shoreline	Required index
"Water"	Volume	Satisfaction degree of minimum ecological water level	Required index
	Quality	Quality of water	Required index
		Lake nutritional status	Required index
		Sediment pollution status	Optional index
		Water self-purification capacity	Required index
Biology		Macrobenthic Invertebrate Biological Integrity Index	Optional index
		Fish retention index	Required index
		Water and bird conditions	Optional index
		Phytoplankton density	Required index
		Macrophyte coverage	Optional index
Social Service Functions		Flood control compliance rate	Optional index
		Shoreline utilization management index	Optional index
		Comprehensive benefits of Green Road construction	Optional index
		Public satisfaction	Required index

4 DONGSHAN LAKE HEALTH EVALUATION, OVERALL CHARACTERISTICS ANALYSIS AND PROTECTION COUNTERMEASURES

4.1 Dongshan Lake Health Evaluation based on Multi-Dimensional Index System

With reference to the evaluation methods and standards of the Technical Guidelines, from the perspectives of the four criterion levels of "Basin", "Water", biology, and social service functions, the health evaluation indices of the Dongshan Lake are assigned scores on the basis of literature review, survey visits and field investigations. According to the weight of each health evaluation index of the Dongshan Lake, the index layer and the criterion layer are weighted layer by layer, and the specific calculation adopts Formula (1).

$$RHI_i = \sum_{}^{m} \left[YMB_{mw} \times \sum_{}^{n} \left(ZB_{nw} \times ZB_{nr} \right) \right] \quad (1)$$

In Formula (1), RHI_i is the comprehensive score of the lake health in the i-th evaluation Lake area; ZB_{nw} is the weight of the n-th index of the index layer; ZB_{nr} is the score of the n-th index of the index layer; YMB_{mw} is the weight of the m-th criterion layer. According to the Technical Guidelines, the Dongshan Lake set up three evaluation areas (Figure 2), i=3.

The comprehensive health score of Dongshan Lake is calculated by formula (2).

$$RHI = \sum_{i=1}^{R_S} \left(RHI_i \times W_i \right) \left(\sum_{i=1}^{R_S} \left(W_i \right) \right)^{-1} \quad (2)$$

In Formula (2), RHI is the comprehensive score for the lake health; RHI_i is the comprehensive score for the lake health of the i-th evaluated lake area; W_i is the water surface area of the i-th evaluated lake, km^2; Rs is the number of evaluated lake areas.

The final health evaluation result of the Dongshan Lake was calculated, as shown in Table 3, Table 4, Figure 2 and Figure 3. It can be seen from Table 3 that the overall scores of the four standard layers—Basin", Water, Biology, and Social Service Functions of the Dongshan Lake are 86.85, 67.80, 39.37 and 97.07, respectively. The Water standard tier scored 67.80, which is lower, and the overall score of the criteria layer is the lowest, only 40.46. The comprehensive health evaluation score of the Dongshan Lake is 74.70.

Table 3: Multi-dimensional Index Assignment of the Dongshan Lake Health evaluation.

Criterion layer	Criterion layer weight (YMB_{mw})	Index layer		Index layer weight (ZB_{nw})	assigned score (ZB_{nr})
"Basin"	0.2	Lake connectivity index		0.19	45.00
		Lake area shrinkage ratio		0.27	100.00
		Natural conditions of shoreline		0.27	90.00
		Degree of illegal development and utilization of water shoreline		0.27	100.00
		Overall score			86.85
"Water"	0.3	Water volume	Satisfaction degree of minimum ecological water level	0.30	75.00
		Water Quality	Quality of water	0.20	40.00
			Lake nutritional status	0.20	49.00
			Sediment pollution status	0.10	75.00
			Water self-purification capacity	0.20	100.00
		Overall score			67.80
Biology	0.2	Macrobenthic Invertebrate Biological Integrity Index		0.18	15.00
		Fish retention index		0.23	7.00
		Water and bird conditions		0.18	75.00
		Phytoplankton density		0.23	31.12
		Macrophyte coverage		0.18	80.00
		Overall score			39.37
	0.3	Flood control compliance rate		0.24	100.00
		Shoreline utilization management index		0.24	100.00

Criterion layer	Criterion layer weight (*YMBmw*)	Index layer	Index layer weight (*ZBnw*)	assigned score (*ZBnr*)
Social Service Functions		Comprehensive benefits of Green Road construction	0.24	97.00
		Public satisfaction	0.28	92.10
		Overall score		97.07
Comprehensive health evaluation score of the Dongshan Lake (RHI)				74.70

Table 4: Comprehensive health evaluation score of the Dongshan Lake.

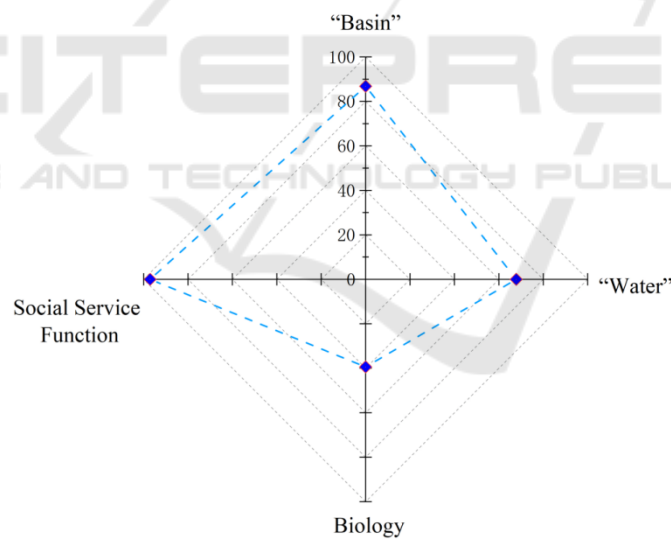| Lake Zoning	Water surface area (*Wi*, km²)	Proportion of zoning area to the total area	Zoning score (*RHIi*)	Comprehensive score (*RHI*)
D1	0.09	25.71%	73.10	
D2	0.10	28.57%	72.74	74.70
D3	0.16	45.71%	72.95	

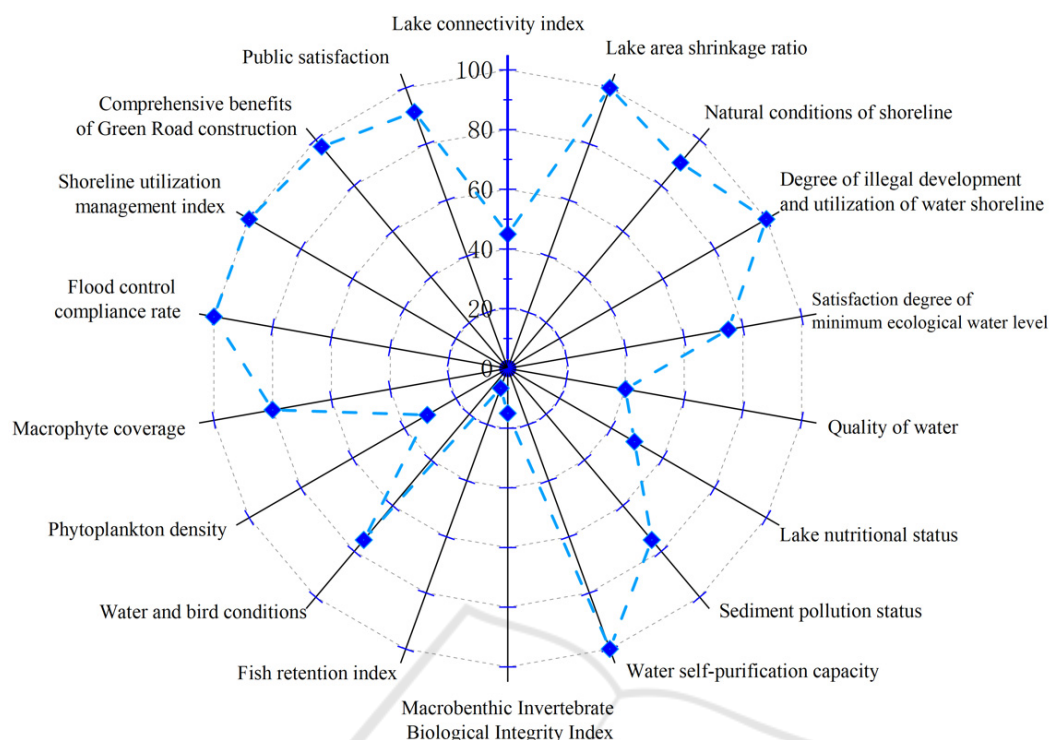Figure 2: Health criteria layer of the Dongshan Lake scoring diagram.

Figure 3: Health evaluation indices of the Dongshan Lake scoring diagram.

4.2 Analysis of the Overall Health Characteristics of the Dongshan Lake

From the perspective of each criterion layer of the Dongshan Lake, the "Basin" criterion layer has a score of 86.85, which is in a healthy state, the "Water" criterion layer has a score of 67.80, which is in a sub-health state, the biological criterion layer has a low score of 39.37, which is in an unhealthy state; the social service function criterion layer has a relatively high score of 97.07, which is relatively healthy. The Dongshan Lake has a total score of 74.70 in the health evaluation which is between 60 and 75. It can be seen that the Dongshan Lake has defects in water ecological integrity and biodiversity, and its health status is generally in a sub-healthy state. According to the health evaluation indices, criterion layers and comprehensive scores of the Dongshan Lake, and referring to the lake health evaluation grading table in the Technical Guidelines (shown in Table 5), the Dongshan Lake was comprehensively assessed as a Class-III lake.

Table 5: Classification table of the lake health evaluation.

Lake classification	Health status	Scoring range (RHI)
Class I	Very healthy	90≤RHI≤100
Class II	Healthy	75≤RHI＜90
Class III	Sub-healthy	60≤RHI＜75
Class IV	Unhealthy	40≤RHI＜60
Class V	Inferior state	RHI＜40

4.3 Countermeasures and Suggestions for the Dongshan Lake Protection

According to the results of the health evaluation of the Dongshan Lake, it has defects in water ecological integrity, anti-disturbance resilience and biodiversity, and is in a sub-healthy state. It should strengthen daily maintenance and supervision, take comprehensive treatment and restoration measures, appropriately increase ecological restoration projects, timely repair local defects and eliminate hidden dangers affecting

health. Combining with the health evaluation of the Dongshan Lake, several countermeasures and suggestions for protecting the Dongshan Lake are put forward.

Firstly, water environment treatment should be consolidated. The pollution problem of the Dongshan Lake can be fundamentally solved by adhering to the water control policy of source control, pollution interception, desilting, water replenishment and management, implementing and promoting grid water control, tackling difficulties in meeting the standards of drainage units, and a series of practices such as Three Sources, Four Washing and Five Cleaning, which have been proven effective.

Secondly, the comprehensive treatment and restoration measures of water ecology should be strengthened. While doing a good job in the Three Sources, Four Washing and Five Cleaning of the Dongshan Lake, the ecological revetment project of the Dongshan lake shoreline shall be implemented. At the same time, focusing on the actual needs of improving the water ecological integrity, anti-disturbance elasticity and biodiversity of the lake, the ecological restoration projects, such as the implementation of biological manipulation, multiplication and release measures, should be appropriately increased.

Thirdly, the connectivity of the Dongshan Lake should be restored. The Dongshan Lake should implement the river and lake connectivity project to ensure the overall connectivity of the lake. At the same time, on the premise of ensuring flood control safety, it should be optimized the linkage mechanism of Dongshan Lake sluice and pump to realize the small cycle of the Dongshan Lake, the Xinhepu River and the Dongshan Lake, the large cycle of the Pearl River, the Dongshan Lake, the Xinhepu River, the Donghao River and the Pearl River, so as to make the lake water truly live water (Figure 1).

Fourthly, precise management should be strengthened. Taking the implementation of the LCS and the most stringent water resources management system as the starting point, it should be strengthen the protection of lake water resources, the management and protection of lake water shoreline, the prevention and control of water pollution, the treatment of water environment and the restoration of water ecology, etc., prepared and improved the "One Lake, One Policy" plan on a rolling basis, promoted the systematic governance of the whole basin and effectively improved the management level of the Dongshan Lake health.

At last, it is necessary to implement the responsibility management system, strengthen the assessment mechanism, and effectively improve the management effectiveness, so as to protect the health of the Dongshan Lake.

5 CONCLUSION

Rivers and lakes are important carriers of water resources and have important ecological, environmental and social service functions [11]. With the rapid development of economy and society, many river and lake ecosystems are gradually damaged or even destroyed. Maintaining and restoring river and lake health has gradually become an important task and central work of lake management. River and lake health evaluation is an important basic work to strengthen the management and protection of rivers and lakes, and it is an important means to test the Famous and Real of RCS and LCS. With the in-depth implementation of RCS and LCS, the health evaluation of rivers and lakes has attracted much attention. In this paper, focusing on the comprehensive management and protection of lakes, with the help of the multi-dimensional index system of lake health evaluation in the Evaluation Guidelines and Technical Guidelines, the Dongshan Lake in Guangzhou was taken as an example to study and determine the multi-dimensional health evaluation index system. Utilizing the index system, the health evaluation and overall health characteristics analyzation of the Dongshan Lake were carried out. According to the health evaluation indices, criterion layers and comprehensive scores, the Dongshan Lake was comprehensively assessed as a Class-III lake. Finally, combined with the health evaluation of the Dongshan Lake, this paper put forward relevant countermeasures and suggestions for its management and protection.

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REFERENCES

Cheng Y. H., 2019. *Research on Health Evaluation of Yamaguchi Lake Reservoir*, Harbin: Heilongjiang University Library, 1 p.

Hu W. ., Salomonsen J., Xu F. L., Pu P. M., 1998. A model for the effects of water hyacinths on water quality in an experiment of physico-biological engineering in Lake Taihu, China. *Ecological Model.* 107: 171-188.

Jones M. L., Taylor W. W., 1999. Challenges to the implementation of the ecosustem approach in the Great Lakes basin. *Aquatic Ecosystem Health & Manag,* 2(2): 249-254.

Ladhar S. S., 2002. Status of ecological health of wetlands in Punjab, India. *Aquatic Ecosystem Health & Management,* 5: 457-465.

Liu L. Y., Li Y., Wang X. G., 2020. The background and significance in the issuance of the Guidelines for River and Lake Health Assessment (Trial). *China Water Resources,* (20): 1-3.

Pu P. M., Wang G. X., Li Z. K., Hu C. H., Cheng B. J., Cheng X. Y., Li B., Zhang S. Z., Fan Y. Q., 2001. Degradation of healthy aqua-ecosystem and its remediation: theory, technology and application. *Journal of Lake Sciences,* 13: 193-203.

Steedman R. J., 1994. Ecosystem health as a management goal. *Journal of the North American Benthol Science,* 13: 605-10.

Wang S. M., Dou H. S. 1998. *Lake records of China*, Beijing: Science Press.