Qualitative and quantitative evaluation of small and medium-sized rivers based on data resources

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Abstract. Over the past three centuries, due to the improvement of the understanding of the natural environment and social service function of rivers, many countries in the world have started the research and practice of river health evaluation. However, the connotation and definition of river health has not formed a unified standard around the world. Recently, there are many studies on the ecological health of large rivers in China, and a relatively acceptable hydrological and water quality monitoring system has been established for those large rivers. However, the health evaluation of various small and medium-sized rivers is still in the preliminary stage. Though many commonly used evaluation methods have been introduced in China, it is still difficult to carry out health evaluation in small and medium-sized River areas due to the lack of basic data, the difficulty of real-time monitoring, the complexity of index calculation formula and other factors. Based on the current situation of construction, management and monitoring of small and medium-sized rivers in China, this study uses qualitative and quantitative methods to evaluate the health of typical small and medium-sized rivers, and compares the evaluation systems and results of the two methods in order to find a suitable river health evaluation method for typical small and medium-sized rivers in China under limited data resources.

1. Introduction
Rivers have many functions, such as water supply, irrigation, power generation, shipping and recreation. For a long time, human beings attach great importance to the development and utilization of the social functions of rivers to meet the needs of human society, however, ecological functions of rivers have been neglected for a while[1-4]. For example, human beings have built large-scale slope land reclamation to increase grain production. Moreover, in order to meet the needs of water supply, flood control, power generation and shipping, a large number of water conservancy projects have been built. Various human activities have greatly changed the natural status of rivers, resulting in serious degradation of river ecosystems, such as shown in Figure 1 [5-7].

Since 1920s, researchers paid lot of their attentions to rivers health index system and evaluation method, those studies have developed a series of index system and evaluation method. Evaluation methods such as RIVPACS, AUSRIVAS, IBI, RCE, ISC, RHS and RHP are widely applied in various countries around the world [8-14]. The characteristics of typical river health evaluation methods are shown in Table 1 [13-17].

![Image](Figure 1)
Figure 1. River ecology and human society

Since 1990s, China has begun to attach importance to ecological protection and restoration in river management. The research of river health evaluation has gradually become an important theoretical basis for river ecological restoration. Tang Tao and his group first introduced the concept of river ecosystem health and health evaluation abroad into China in 2002. But their study did not attract much attention in China [6]. In October 2003, Li Guoying put forward the concept of "river life" at the first International Conference on the Yellow River, calling on river managers to "leave basic discharge for the river to maintain its own ecological balance". This conference triggered extensive discussions and studies on river health in China [10,11]. After that, the theory, method and practice of river health in China have been further developed. Different experts and scholars as well as major river basin organizations in China have developed their own concept, evaluation index system and evaluation methods of river health [14]. At present, river health has become the main goal of sustainable development of water resources and integrated management of river basins in China, but the research on river health in China is still in early stage, and there is no unified scientific viewpoint and technical specification of river health evaluation in China[18].

Table 1. Famous river health evaluation methods

| Type             | Evaluation method | Founder | Year | Utilization country |
|------------------|-------------------|---------|------|---------------------|
| Predictive model | RIVPACS           | Wright  | 1984 | USA, Canada         |
|                  | ALSRIVAS          | Simpson | 1994 | Australia           |
|                  | IBI               | Karr    | 1981 | Germany, UK         |
| Multi-metrics    | ISG               | Ladsoo  | 1999 | USA, UK             |
| method           | RCE               | Petersen| 1992 | UK, Canada          |
|                  | RHS               | Raven   | 1997 | UK                  |
|                  | RHP               | Rowntree| 1994 | USA, Australia      |

2. Methodology

2.1 Data Resources and River Health Evaluation

Detailed on-site investigation and historical monitoring data are the basis of river health evaluation in the world. The international river monitoring has a long history, especially in the United States and Western European countries. Therefore, the river health evaluation carried out in these countries is mostly based on biological indicators, assisted by long series of hydrological and water quality monitoring data. Which lead to a better evaluation effect and provide a basis for river management and basin development. On the other hand, biological monitoring is seldom carried out in China for small and medium-sized rivers except the Yangtze River and the Yellow River because of the late development, imperfect monitoring system and limited investment scale. The corresponding hydrological and water quality monitoring data are also very limited, which makes it difficult to carry out river health evaluation in China, especially for small and medium-sized rivers. The author
participated in the project of "Health Evaluation of Important Rivers in Zhejiang Province" (2016-2018), accumulated data resources of many rivers in Zhejiang Province, found that some small and medium-sized rivers are lack of monitoring data, which has obviously affected on river health evaluation. Taking typical small and medium-sized rivers in Zhejiang Province as an example, according to the lack of river data resources, the qualitative and quantitative evaluation methods of river health are proposed respectively. Different evaluation methods are used to evaluate the health of small and medium-sized rivers in Zhejiang Province. The contents and results of the two methods are compared and analyzed, and the river health under different data resource conditions is explored.

2.2 Current situation of river data resources in China
Dense population and fierce competition embarrassed China, hence, the usage of ecological and economic water resources in China shows great differences from European and American countries. This highly competitive water use highlights the development and utilization of rivers by human society, which leads to more emphasis on maintaining the river health. In China, social data indicators are more taken into account in river health evaluation system, which reflects China's concern for social development. On the other hand, compromises are also made in the evaluation due to the insufficient basic data resources of small and medium-sized rivers. River health evaluation methods require enough data resources. Indeed, researchers have put forward their own scientific opinions of river health evaluation indicators and methods in the past several decades. However, up to now, a unified or widely recognized river health evaluation index system is still missing in China. The health evaluation of small and medium-sized rivers in China still focuses on the evaluation of river water quality by means of chemical indicators and a very small amount of biological monitoring. Long-term monitoring data of river hydrology and water quality are relatively scarce, and the systematic biological monitoring is seldom in China. Therefore, it is still necessary for China to establish different river health evaluation system based on different data resources.

2.3 Qualitative and quantitative evaluation of river health

2.3.1 Qualitative evaluation method
In this study, MEM-RHS (Multimetric Evaluation Method - River Habitate Survey) method is adopted as the qualitative river health evaluation method. based on the RHS (River Habitate Survey) method, which is widely used in the UK. Some evaluation indicators were adjusted according to the current situation of rivers in China. It is suitable for those rivers which have undergone certain artificial transformation, and can better connect evaluation indices with river morphology, biological composition and habitat system. The qualitative evaluation system and indicators are shown in Table 2.

2.3.2 Quantitative evaluation method
In this study, Analytic Hierarchy Process (AHP) is adopted as the quantitative river health evaluation method. AHP method is a common used method to determine the relative weight of each index of a certain target. Compared with other methods, AHP method requires more data, but the deviation caused by human is less.

According to the principle of AHP method, the weight of individual evaluation indices in the system are scored, and the final scores of each level are summarized to obtain the total score of river health evaluation system. The scoring equation is as follows:

\[
TG = \sum_{j=1}^{n} \left( \sum_{i=1}^{m} (A_j \times P_i) \right) C_i
\]

(1)

Where, \(TG\) is the score of a single level, \(A_j\) is the weight coefficient of the single index at the certain level, \(P_i\) is the evaluation score of the single index at the certain level, \(C_i\) is the weight coefficient of the certain level.
Table 2. Evaluation of Majinxi river based on qualitative method

| Target level | Criteria                    | Indicators                                                                 | Reject condition                                      | Results  |
|--------------|-----------------------------|----------------------------------------------------------------------------|-------------------------------------------------------|----------|
| Ecoology     | Development of the river bank | If the beach area is too small to the animals                               | o (Positive)                                         |          |
|              | Riparian zone status        | If man-made damage exists on the riparian zone                              | o (Positive)                                         |          |
|              | Habitat diversity           | If the overall species of organisms are simple. The number of species is less than 3. | o (Positive)                                         |          |
| Water resources | Sensory of water quality    | If the water is muddy and smelly                                            | o (Positive)                                         |          |
|              | Water resources development rate | If water resources development rate is greater than 40%                     | o (Positive)                                         |          |
|              | Condition of intake and outlet | If illegal sewer discharge outlet exists.                                 | o (Positive)                                         |          |
|              | Status of sand and stone resources exploitation | If illegal mining exists                                                  | o (Positive)                                         |          |
| River health | Ecological condition of embankment projects | If river is straight, no curve exists.                                    | ● (Negative)                                         |          |
|              | Ecological condition of river blocking projects | If there are no ecological discharge facilities.                           | o (Positive)                                         |          |
|              | Horizontal and vertical connectivity of rive network | If the water conservancy engineering buildings block the river sections, the water system is not connected. | o (Positive)                                         |          |
|              | Landscape                   | If the landscape style is not in harmony                                    | o (Positive)                                         |          |
| Engineering project | Laws and systems    | If the management laws and systems are incomplete.                       | o (Positive)                                         |          |
|              | Professional management and team work | If the management team is not professional.                              | o (Positive)                                         |          |
|              | Facility integrity and convenience | If the facilities are not complete.                                   | ● (Negative)                                         |          |
|              | Effectiveness of execution  | If the annual execution is not found.                                     | o (Positive)                                         |          |

2.3.3 River health levels
Referring to Table 2 and Table 3, ecological judgment was adopted for the qualitative evaluation of river health, while computational scoring was adopted for the quantitative evaluation of river health. River health is then divided into 5 levels, as shown in table 4.

3. Case study

3.1 Overview
Majinxi river is selected as an evaluation case in this study. Majinxi river, with a total length of 89.16km, is the largest river in Kaihua city, Zhejiang province. It is the upstream of the Qu river and one of the sources of the Qiantang river. Majinxi river flows through Qixi town, Xiashan town, Majin town, etc. The upstream of Majinxi river is a narrow mountainous river, while the downstream becomes plain and mild.
Table 3. Evaluation of Majinxi river based on quantitative method

| Target level | Criteria | Indicators | Evaluation | Weight | Score | Evaluation | Weight | Score | Evaluation | Weight | Score | Sub-goal |
|--------------|----------|------------|------------|--------|-------|------------|--------|-------|------------|--------|-------|----------|
| Main target  | Sub-goal |            |            |        |       |            |        |       |            |        |       |          |
| Natural function | Hydrology | Guarantee rate of ecological flow | 100 | 0.7 | 70 | | | | | | | |
| | | Variation rate of flow process | 75 | 0.3 | 22.5 | | | | | | | |
| Environment | Water quality comprehensive index | 75 | 0.6 | 45 | 75 | 0.3 | 22.5 | | | | |
| Ecology | Riparian zone status | 50 | 0.4 | 20 | 80 | 0.3 | 24 | | | | |
| | Habitat diversity | 100 | 0.6 | 60 | | | | | | | |
| Social function | Safety | Anti-flooding capability | 75 | 0.2 | 15 | | | | | | 79.7 |
| | Flood protection guaranteed rate | 100 | 0.8 | 80 | | | | | | | |
| Resource | Utilization index of water resources | 25 | 0.6 | 15 | 55 | 0.4 | 22 | | | | |
| | Water function area compliance rate | 100 | 0.4 | 40 | 74 | 0.4 | 29.6 | | | | |
| Civilization | Public-water satisfaction | 70 | 0.5 | 35 | | | | | | | |
| | Cultural value index | 70 | 0.5 | 35 | 70 | 0.2 | 14 | | | | |
| | Social benefit index | 100 | 0.7 | 70 | | | | | | | |

Table 4. River health levels

| Levels | Qualitative evaluation Negative indicators | Quantitative evaluation Main target score | River status |
|--------|--------------------------------------------|----------------------------------------|--------------|
| I      | 0                                          | [80,100)                                | Ideal        |
| II     | 1-2                                        | [60,80)                                 | Healthy      |
| III    | 3-6                                        | [40,60)                                 | Sun-healthy  |
| IV     | 7-10                                       | [20,40)                                 | Unhealthy    |
| V      | 11-15                                      | [0,20)                                  | Sick         |

In this study, the main stream of Majinxi river, namely from Misai section to Xinxia bridge, was selected for the river health evaluation. The main stream of Majinxi river is 16.36km long and the basin area is about 797km². It is a typical small and medium-sized river, which mainly flows through Chengguan town of Kaihua town, as shown in Figure 2. Therefore, although the characteristics of mountainous rivers are obvious, the social service function of this section is also outstanding.

In this study, river data resources are collected to evaluate the health of Majinxi river, such as: (1) Hydrological data: The flow data of Misai hydrological monitoring station is used in the quantitative evaluation. (2) Water quality data: The water quality data are mainly obtained by on-site survey or the analysis of the regular monitoring data.(3)Social data: Social service function indicators are obtained by on-site survey, field consultation, public survey and other methods.
3.2 Evaluation results
The qualitative evaluation results can be seen in Table 2. Among all the indicators, the facility integrity and the ecological condition of embankment project are deficient. These two indices are determined as negative indicators, while the other indices meet the requirements of ecological function. Therefore, for Majinxi river, only two of all the indicators in the qualitative evaluation system are failed to meet the requirements of ecological function, and the qualitative evaluation result of the health of Majinxi river is healthy.

The quantitative evaluation results can be seen in Table 3. The final score is 79.7. The quantitative evaluation result of Majinxi river is also in the healthy status. According to the score of the sub-target layer, the natural ecological status is close to the social service function. The scores of the criterion layer are also similar, among which the scores of hydrology and water security are relatively high, and the scores of utilization of water resources are relatively low. The river health evaluation result show good agreements with the function of Majinxi river itself.

3.3 Comparison and analysis
Comparing the qualitative river health evaluation in Table 2 and the quantitative river health evaluation in Table 3, it can be found that fewer basic data are required for qualitative evaluation, while the quantitative evaluation requires a large amount of basic data, more calculation and analysis of basic data are also executed in order to obtain the score of each indicator during quantitative evaluation.

As also can be seen in the overall Majinxi river health evaluation results, firstly, the qualitative evaluation system adopts the multi-index evaluation method and the ecological judgment, which eventually forms the qualitative judgment conditions based on the multi-index system. While the quantitative evaluation system mainly focuses on computational evaluation and adopts the analytic hierarchy process to form a comprehensive score of 79.7. Secondly, the results of qualitative and quantitative evaluation on the health status of Majinxi river are similar, considering Table 4, both methods show healthy status of Majinxi River. Thirdly, although both of these two kinds of river health evaluation methods proposed in this paper can analyse and evaluate the river health condition, however, due to the different data resources requirement, the evaluation process and content of these two methods are still different. In the process of qualitative evaluation, more field works are needed, but all indices can be directly evaluated through the data information obtained from field works. Quantitative evaluation, on the other hand, needs more complicated data collection and calculation. Large amount of data resources and high computational complexity are the main characteristics of quantitative evaluation, which show the differences from the qualitative evaluation.

From the perspective of their demand for data resource, it is obvious that qualitative evaluation has more application value and the practical operation is also more convenient than quantitative evaluation. It is more applicable for the health evaluation of small and medium-sized rivers in China, most of which have not established a complete monitoring system and lack of data resources. However, the
quantitative evaluation with enough data resources will be a better choice in China if a complete and effective river monitoring system has been established in the future.

4. Conclusion
This study establishes both qualitative and quantitative evaluation systems for river health evaluation based on different data resources. A typical small and medium-sized river is selected as an evaluation case. Special attentions are paid to the applicability, operability and accuracy of these two methods.

River health evaluation can be used to determine the goal of maintaining and improving of the river. It is also important for river management decisions. Therefore, the future work of river health evaluation will be focused on the comprehensive evaluation of river ecosystem health status, which is able to formulate the target of water resources management and the corresponding river management countermeasures.

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