Application and Analysis of Different Evaluation Methods in Water Quality Evaluation of Jinxiuchuan Reservoir

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Abstract. At present, there are many water quality assessment methods. How to screen suitable methods for scientific evaluation of water quality is a basic and important work in environmental protection. In this study, based on the water quality monitoring data of Jinxiuchuan Reservoir in Jinan City, Shandong Province for the period from 2015 to 2017, according to the principle of selecting water quality indicators and environmental quality standards for surface water, the following six indicators were selected to reflect the water quality such as dissolved oxygen (DO), permanganate index (CODMn), Biochemical Oxygen Demand (BOD5), ammonia nitrogen (NH4+-N), total nitrogen (TN), total phosphorus(TP), and three evaluation methods, including single factor evaluation, gray relational evaluation method and fuzzy comprehensive evaluation method, were used to evaluate the water quality condition of Jinxiuchuan Reservoir. The rationality and defects of these three methods were also explored by comparing their results. The results showed that: (1) the results of water quality assessment were greatly affected by the evaluation methods; (2) the water quality obtained by the gray relational evaluation method was the best; (3) the results obtained by the single factor evaluation and the fuzzy comprehensive evaluation method were similar. In order to accurately assess the water quality of surface water, different assessment methods are recommended for comprehensive analysis.

1. Introduction

Water quality assessment methods and the scientific rationality of their results have always been a hot topic in the discussion of water environment management in the world [1]. Water quality assessment is an important task in the supervision and management of water resources. The development trend as well as the changes of water quality in the past, present and future in a certain area can be accurately understood by the evaluation of the water quality. It is necessary to find out major pollution factors and major pollution sources that affect the water quality of the area, so as to formulate pollution source treatment plans and comprehensive prevention plans and measures with purpose. A water quality evaluation method can be widely used in environmental management, not only due to its scientific nature and accuracy, but also its simple calculation and easiness to grasp [2]. The diversity of water quality indicators and the complex environment make the assessment of water quality both precise and ambiguous. Therefore, it is not always possible to make accurate assessments only based on the status of certain contaminants [3]. On one hand, the reliability of water quality assessment

results depends on the accuracy of the test data, and on the other hand, it depends on scientific evaluation methods. The present research mainly focuses on the actual situation in the study area and uses a variety of indicators and methods to comprehensively assess the water quality [4]. In this study, taken Jinxiuchuan Reservoir as an example, different evaluation methods were applied and the results were analysed by comparison in order to objectively evaluate its water quality.

2. Data sources and Research Methods

2.1. General situation of Study Area
Jinxiuchuan Reservoir, located in midstream of Jinxiuchuan River, the main tributary of Yufu River in southern mountain areas of Jinan City, was used as the study area. Jinxiuchuan River belongs to the Yellow River system and merges into the Wohushan Reservoir. The reservoir lies between $36°50'E$-$36°52'E$ and $117°14'$-$117°18'$ N with the drainage area of 166 km2, and the average annual water supply 0f 20 million m3. Study area has sub humid warm temperate continental monsoon climate, where the precipitation is mainly concentrated in summer, with rain and heat during the same period. In the initial stage of the reservoir operation, it mainly provides living and agricultural water needs in the surrounding areas. With the development of the economy and changes in local geographical conditions, the reservoir is currently mainly used to supply water for urban life in Jinan City, especially in Licheng District, and plays a very important role in water supply for urban life [5]. Jinxiuchuan Reservoir has been used for urban water supply since 1987, and some water quality problems have appeared due to historical issues. The garbage and sewage generated by residents near the reservoir are discharged directly into the reservoir without treatment. Due to lack of fence, villagers and tourists freely entered the reservoir area for cultivation and amusement. Residues such as chemical fertilizers and pesticides applied to farmland directly enter the reservoir with rainwater, which resulted in pollution of water sources and increased reservoir eutrophication [6].

According to Surface Water Environmental Quality Standard (GB 3838-2002) and environment function and protection target of surface water, water quality must meet Grade II in Jinxiuchuan Reservoir, as a first-grade protection area for drinking water sources.

2.2. Data Sources
In this study monthly water quality data of Jinxiuchuan Reservoir from 2015 to 2017 were collected, supplied by Jinxiuchuan Reservoir Office. Such six items as dissolved oxygen (DO), permanganate index (COD_{Mn}), Biochemical Oxygen Demand (BOD_5), ammonia nitrogen (NH_4^+-N), total nitrogen (TN) and total phosphorus (TP) were chosen to evaluate water quality. The statistical description of the original data is shown in Table 1. Monthly and quarterly average detection values were analyzed to evaluate the water quality changes in each month and quarter of the reservoir.

Table 1. Statistical description of original water quality variables from 2015 to 2017.

Index name	Index value/(mg·L⁻¹)			Standard deviation
	Min	Maximum	Average value	
DO	5.1	12.4	8.915	1.872
COD_{Mn}	1.65	3.95	2.623	0.566
BOD_5	0.52	2.61	1.724	0.527
NH_4^+-N	0.025	0.545	0.079	0.091
TN	0.6	5.54	3.041	1.344
TP	0.01	0.05	0.024	0.011

2.3. Water Quality Evaluation Methods

2.3.1. Single factor evaluation. Single factor evaluation index is a dimensionless index. The test results of selected pollution factors are compared with their respective criteria, and the water quality for each factor is determined. The worst water quality index is used as the whole water quality level. Single factor assessment method is the pessimistic evaluation principle established in the current national water quality standards.

2.3.2. Gray Correlation Analysis. The gray relational evaluation method derives from the gray system theory [7]. The data of the water quality monitoring section is used as the reference series [$X_0(t)$], and the data at various levels of the water quality evaluation standard is the comparison series [$X_i(t)$]. The correlation coefficient between the reference series and the comparison series is calculated, and then the weighted correlation degree is used for the correlation coefficient. Finally, the degree of relevance is sorted, in which the highest degree of association is the water quality level of the section.

2.3.3. Fuzzy comprehensive evaluation method. Since the water environment is an uncertain system, it is difficult to determine the boundary point whether water environment is non-polluted or polluted, which is ambiguous. Therefore, in the comprehensive evaluation of water environment quality, fuzzy mathematics is widely used to solve the uncertainty and ambiguity of the water environment, with more objective and scientific evaluation result. The fuzzy comprehensive evaluation method supposes that there are a lot of fuzzy and uncertain factors in water quality types and grading standards [8]. The basic idea of evaluation is: The sample matrix and the standard matrix are established according to the monitoring value and evaluation standard. Then the membership degree matrix is set up according to the degree of membership of all levels of the water quality index. The weight set of the parameters of the water quality index is multiplied by the membership degree matrix, and the comprehensive evaluation set is obtained. Finally, the water quality level is determined according to the principle of maximum membership degree [9]. The degree of membership of the water quality standards corresponding to the water body can reflect the fuzzy of the water quality level of the water body [10].

2.4. Water quality grading standards
Surface Water Environmental Quality Standard (GB3838-2002) is adopted and specific grading standards are shown in Table 2.

Table 2. Environmental quality standards for surface water. $mg \cdot L^{-1}$

Index name	I	II	III	IV	V
DO	≥7.5	≥6	≥5	≥3	≥2
COD_{Mn}	≤2	≤4	≤6	≤10	≤15
BOD_5	≤3	≤3	≤4	≤6	≤10
NH_4^+-N	≤0.15	≤0.5	≤1	≤1.5	≤2
TN	≤0.2	≤0.5	≤1.0	≤1.5	≤2.0
TP	≤0.01	≤0.025	≤0.05	≤0.1	≤0.2

3. Results and Discussion

3.1. Water Quality Evaluation Results

3.1.1. Monthly Water Quality Evaluation Results. Water quality results for each month are shown in Figure 1. The single factor evaluation results showed that the water level in 2 months (June and July 2016) was Grade III, in 2 months (August 2015 and May 2016) was Grade IV and in 6 months (June and July 2015, March, April 2016 and October and November 2017) was Grade V. The remaining 26

months were worse than Grade V. By gray relational evaluation method only 3 months (July, August and October 2016) was Grade II and the remaining 33 months were Grade I. The results of the fuzzy comprehensive evaluation method, quite different from the other two methods, showed that 2 months (June and July 2016) were Grade II, 2 months (August 2015 and May 2016) were Grade III, 6 Months (June, July, September, December 2015, April, August 2016) were Grade IV and the remaining 26 months were Grade V.
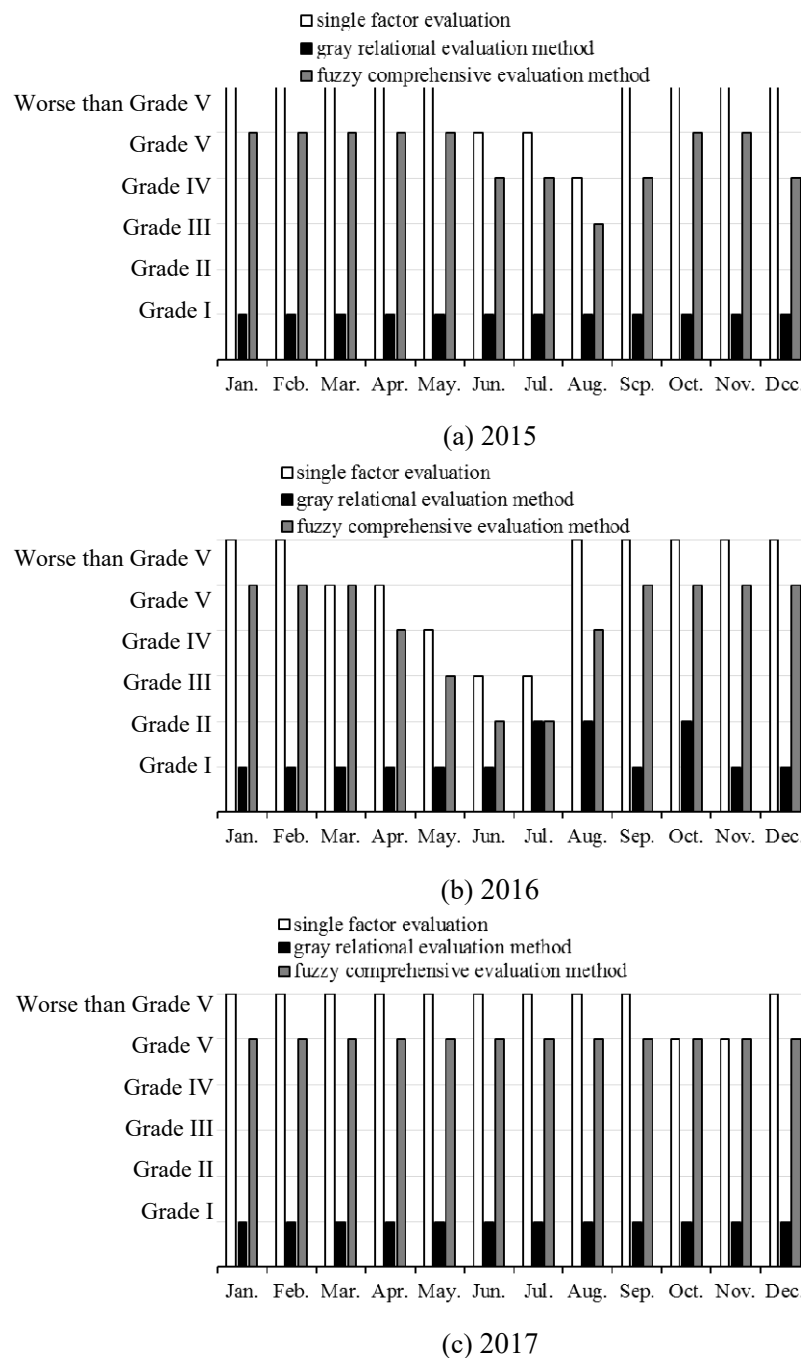

(a) 2015

(b) 2016

(c) 2017

Figure 1. Monthly water quality results of Jinxiuchuan Reservoir by three methods from 2015 to 2017.

3.1.2. Seasonal Water Quality Evaluation Results. The results of the water quality assessment in spring are shown in Figure 2(a). The results of the single factor evaluation showed Grade V in 2016, and worse than Grade V in the remaining two years. The results of the gray relational evaluation method were Grade I for three years. The fuzzy comprehensive evaluation method showed that it was Grade IV in 2016 and Grade V in 2015 and 2017.

The summer water quality assessment results are shown in Figure 2(b). Single factor evaluation results showed Grade V in 2015, and worse than Grade V in the remaining two years. The result of the gray relational evaluation method is Grade I for three years. The results of the fuzzy comprehensive evaluation method showed that it was Grade IV in 2015 and Grade V both in 2016 and 2017.

The results of the autumn water quality assessment are shown in Figure 2(c). Single factor evaluation results showed that three years were worse than Grade V. The results of gray relational evaluation method showed that three years were Grade I. The results of the fuzzy comprehensive evaluation method showed that three years were all Grade V.

The results of winter water quality assessment are shown in Figure 2(d). Single factor evaluation results showed that three years were worse than Grade V. The results of gray relational evaluation method showed that three years were Grade I. The results of the fuzzy comprehensive evaluation method showed that all three years were Grade V.
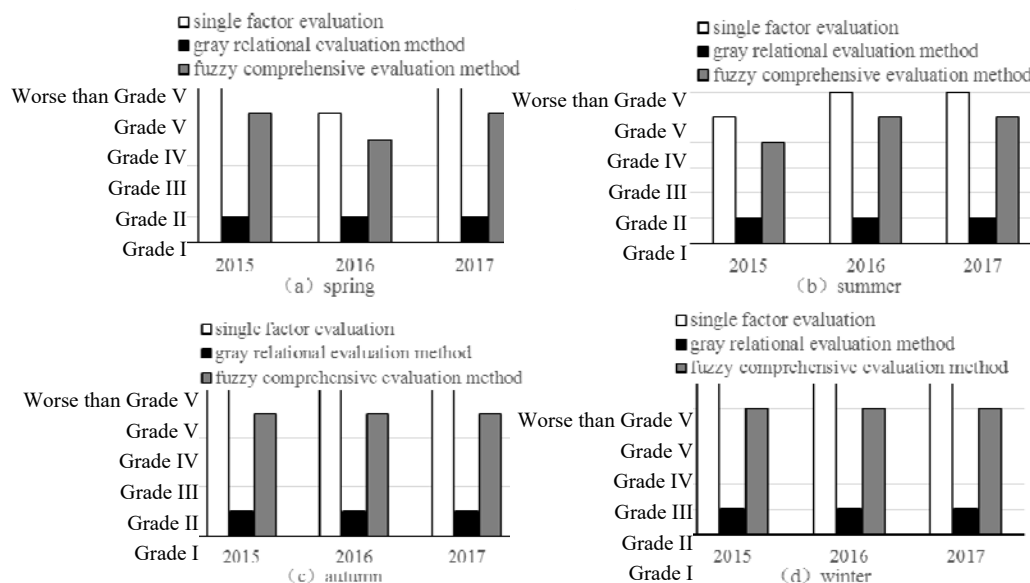

Figure 2. Seasonal water quality results of Jinxiuchuan Reservoir by three methods from 2015 to 2017.

3.2. Comparison of evaluation results

The results obtained by the single factor evaluation and the fuzzy comprehensive evaluation method were similar. Although the same proportion of the results was 6.25%, the proportion of the results differed by one grade was as high as 89.6%, and the ratio of the difference of two grades was as low as 4.2%. The above two methods were affected by the high concentration of TN, causing the water quality to be reduced to Grade V, or even worse than Grade V. In addition to several months, the other evaluation indexes have reached the water quality standard of the Grade II. For example, in August 2015, DO, NH_4^+-N and TP only can meet the standard of Grade III, which means that TN is not the only factor to cause the decline in water quality.

There were big differences between the results by the three methods. The results obtained by the single factor evaluation and the gray relational evaluation method were far different. Except for a difference of one grade in July 2016 and a difference of two grades in June 2016, the other months usually had a difference of three to four grades. Only 2.1% of the results obtained by fuzzy

comprehensive evaluation method and gray relational evaluation method were the same. In addition to the difference of one grade in June 2016 and the difference of two grades in May 2016, the other months generally differ by 3 to 4 grades. In this applied research, it can be concluded that the gray relational evaluation method was superior to the other two methods for water quality evaluation in Jinxiuchuan Reservoir. For example, in June 2016, the result obtained by single factor evaluation was Grade III, and the result of fuzzy comprehensive evaluation method was Grade II, while the gray relational evaluation method was Grade I, superior to the former two methods.

4. Conclusions and Discussions
In this study the quality of water was best evaluated by gray relational evaluation method, and the evaluation grade obtained by single factor evaluation was the worst, and the evaluation result of fuzzy comprehensive evaluation method had the highest consistency with the results of single factor evaluation. However, both the fuzzy comprehensive evaluation method and the single factor evaluation were affected by the total nitrogen content, which made the final evaluation result worse than the actual water quality in Jinxiuchuan Reservoir.

In practical applications, the determination of water quality assessment methods should refer to local water quality protection and water resources development goals, as well as the use of personnel experience. For example, for water quality evaluation of water sources and ecologically fragile areas, single factor evaluation can be used to achieve the strictest management and protection of water resources. However, single factor evaluation follows the one-vote veto principle, and the water quality requirements are too strict and easy to cause more protection than needed for water quality management. For the evaluation of water quality in downstream economic development zones and irrigation areas, gray relational evaluation method can be selected for evaluation to maximize water resources development and utilization. If the user has a wealth of relevant knowledge, it is recommended to adopt the fuzzy comprehensive evaluation method. However, in order to accurately assess the water quality, it is recommended that a variety of evaluation methods be used for comprehensive analysis.

Acknowledgments

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