Comprehensive Evaluation of Water Environment Under “Zero direct discharge of sewage” Project

Fang Zhangbin1*

1 Reservoir Service Center of Yuhuan Agricultural, rural and Water Conservancy Bureau, Yuhuan City, China

*Corresponding author’s e-mail: 406178746@qq.com

Abstract: This paper takes Yuhuan City as the research object, based on the single factor evaluation method, Nemero index method and gray relevance analysis method, selects three indexes of ammonia nitrogen, total phosphorus and permanganate index. By analyzing the main pollutants, the reduction of each pollutant and the differences between different evaluation methods, the effectiveness of water environment governance is evaluated, and then targeted regulatory measures are proposed to further improve water environment. The results show that the main pollutants in Lupu Town, Yuhuan City are NH3-N and TP. The single factor evaluation method and the Nemero pollution index method showed that the water quality categories are mostly type III and type IV. The evaluation results of the gray correlation analysis method are mostly Class II water, and all three methods indicate that most of the sites before the construction meet the Class IV water standard. During the construction process, the single factor evaluation method and the Nemero pollution index method show improvement in water quality, while the grey correlation analysis method showed little change in water quality categories. According to the various indicators and water quality changes, it can be seen that the effect of the zero-drainage project is significant for the improvement of river water quality.

1. Background and Significance

Water resource is an important natural resource, which maintains the natural ecosystem and guarantees the survival and development of human beings. In recent years, due to the unreasonable development and utilization of water resources, as well as various pollutants discharged into water bodies, the water environment problems become increasingly serious. The water resources waste phenomenon is serious, the water pollution event is frequent, the water resources supply and demand contradiction is more and more prominent. In order to improve the water environment, the nation has introduced some regulations and policies. In 2014, China revised the "Environmental Protection Law"[1], put forward the environmental protection strategy of "protection first", enhanced the law enforcement authority of environmental protection departments, strengthened environmental protection supervision and assessment, and clarified that "the nation establishes and improves the ecological protection compensation system" and "implements the emission permit management systems" [2]. In December 2016, The Central Leading Group for Comprehensively Deepening Reform, general Office of the CPC Central Committee and General Office of the State Council successively adopted and issued "opinions on the Comprehensive Implementation of river chief System", calling for the comprehensive implementation of river chief System by the end of 2018[3]. Water quality evaluation in China has gone through a development process from single index, single coefficient to multi-index and multi-coefficient synthesis[5], from simple superposition to mean value and then to weighted
calculation, from single point evaluation to map overlapping to comprehensive evaluation[4]. Liu Wenwen et al. used minimum/maximum autocorrelation factor analysis (MAFA) and dynamic factor analysis (DFA)[5] to analyze the temporal and spatial variations of water quality variables in three typical tributary - trunk stream intersection areas of the Han River from June 2014 to April 2017.

In Yuhuan city, water resource is one of the main restricting factors of local economic development and plays an important role in urban development. With the discharge of domestic, industrial and agricultural pollutants into the water body, the water environment of Yuhuan deteriorates, and many measures have been taken to improve the water environment. The “Zero direct discharge of sewage Project” was carried out for improving water environment. Since the implementation of "five-Water treatment Plan", the water environment in Zhejiang province has improved obviously, but the results of water conservancy exists rebound. In order to solve the problem of "repeated treatment, repeated treatment", Yuhuan launched the project of "zero direct discharge of sewage", by the end of 2018, the city had completed the pilot project of building 1 industrial cluster area, 9 living quarters, 20 other key pollution source control areas and 1 township "zero sewage direct discharge area", by the end of 2019, more than 50% of towns and townships (streets) shall meet the construction standard of "zero sewage direct discharge zone"; By the end of 2020, the whole area of the city will basically reach the construction standard of "zero direct discharge of sewage", and realize that "no sludge and turbid water will be brought into an all-round well-off society". With the progress of water comprehensive treatment and ecological restoration project, it is particularly important to evaluate the effectiveness of "zero direct discharge of sewage" project measures scientifically by evaluating the water quality before and after water environment treatment and analyzing the reduction of each pollutant. The evaluation of water environment quality can judge the current water pollution status according to the water quality monitoring data, evaluation standards and calculation methods of the evaluation target, provide a scientific basis for water environment utilization and management[6], and propose targeted regulation measures for further improving the water environment.

2. Water quality evaluation method

2.1 The single factor evaluation method

The single factor evaluation method is to compare the measured value of the evaluated pollution factor with the environmental quality standard of surface water and the limit value of drinking water to determine the type of water quality. The determination method is to select the worst water quality category as the water quality category among the selected pollution indicators. Determine the main pollutants in the water area, judge whether the pollutants meet the standard, and the multiple of pollutants exceeding the standard limit. This method is simple to calculate, and can intuitively understand the relationship between the measured value and the standard value of each index. Evaluation standard adopts "surface water environment quality standard" (GB3838-2002) regulation IV class water standard, three indexes of permanganate index, ammonia nitrogen and total phosphorus were selected to evaluate the water quality of January, February, March, April, May, September, October and November in 2009. The first 5 months are the water quality before the construction, and September, October and November are the water quality after the construction, the water quality and treatment effect of Yuhuan Lupu watershed before and after water environment treatment were analyzed by comparing the two.

However, the single factor evaluation method also has some defects. This method can only evaluate the classification of water quality by comparative analysis, but cannot quantitatively analyze the monitored value of water quality. At the same time, the single factor evaluation method only takes into full consideration the serious pollution factors, and neglects other pollution factors.
2.2 Nemerow index method

2.2.1. Traditional Nemerow pollution index method. In 1974, Professor Nemerow of Sycamore University in the United States proposed Nemerow Pollution Index method in his book "Scientific Analysis of River Pollution [4]. This method calculates Nemerow pollution index and standard index respectively according to the measured concentration and standard value of the selected water quality index, and compared with the corresponding rating standard index, the rating can be obtained.

2.2.2. Improved Nemerow pollution index method. In the case of actual water pollution, the measured concentration value of some evaluation factors (such as pollution factor TP) is not big, but it has a great impact on the water environment quality. The concentration of pollution factors with high harmfulness is usually smaller, and there is an internal inverse relationship between water quality concentration and harmfulness. Therefore, the weight value of each pollution factor in the water environment quality assessment is increased in the improved Nemerow pollution index method.

2.3. Grey correlation analysis method

Because the water environment system is a complex, unbalanced, nonlinear, small sample grey system, this paper uses grey correlation analysis method to analyze the water quality of Yulupu town. Grey correlation analysis is a method to analyze the correlation degree of each factor in the system. By determining the reference and comparison sequence and dimensionless processing of the original data, the correlation coefficient and correlation degree are calculated to judge the correlation degree between the reference sequence and the comparison sequence. The higher the degree of correlation, the closer the relationship between comparison sequence and reference sequence. According to the principle of maximum correlation degree, the classification of water quality evaluation is determined. Operation steps of grey correlation analysis:

2.3.1 Determine the reference sequence and the comparison sequence. The measured sample sequence is set as the reference sequence, and the evaluation criterion is set as the comparison sequence.

2.3.2 Dimensionless data processing. Dimensionless treatment of water environment quality evaluation standard, the concentration corresponding to the water quality grade is set as $Q_j(k)$, $j$ is the water quality grade, and $k$ is the pollution index.

$$Q_j(k) = \frac{Q_{max}(k) - Q_j(k)}{Q_{max}(k) - Q_{min}(k)}$$

In the formula:
- $Q_j(k)$ is the standardized value of the $k$th pollution index under the $j$th grade;
- $Q_{max}(k)$ is the highest concentration value of pollution index $k$ in grade $j$;
- $Q_{min}(k)$ is the lowest concentration value of pollution index $k$ in grade $j$.

For dimensionless treatment of measured water quality, suppose the measured water quality value $X_i(k), (i=1,2,3...n)$. Most of the evaluation items in the surface water environmental quality standard are the higher the index value, the worse the water environmental quality is. The calculation formula of the dimensionless treatment method for this kind of pollution factor is as follows:

$$Z_i(k) = \frac{M_j - X_i(k)}{M_j - m_j}$$

In the formula:
- $Z_i(k)$ is the standardized value of the pollution index of the $i$ term measured sequence $k$;
- $X_i(k)$ is the concentration value of pollution factor in the $i$ term measured sequence $k$;
- $M_j = \max_{1 \leq i \leq n} X_i(k)$,
- $m_j = \min_{1 \leq i \leq n} X_i(k)$

(1) Calculate the weight of evaluation factors

Superscalar multiple method:
\[ a_k = \frac{c_k}{s_k} \]  
\[ S_k = \frac{1}{n} \sum_{j=1}^{n} S_{ij} \]  
\[ W_k = \frac{a_k}{s_{kj}} \]  

In the formula: \( c_k \) is the measured concentration of the \( k \)th pollutant; \( S_k \) is the standard average value of all levels of the \( k \)th pollutant; \( S_{ij} \) is the standard value of grade \( j \) of the \( k \)th pollutant; \( n \) is the number of intermediate levels in the pollutant standard; \( a_k \) is the weight of the \( k \)th pollutant. \( W_k \) is the normalized weight of the \( k \)th pollutant.

(2) Calculate the grey correlation coefficient

Correlation coefficient formula:

\[ \xi_{ij}(k) = \frac{\min_k \min_p [X_j(i(k)) - X_i(k)] + p \max_k \max_p [X_j(i(k)) - X_i(k)]}{\max_k \max_p [X_j(i(k)) - X_i(k)]} \]  

In the formula: \( P \) is the resolution coefficient, \( 0 \leq P \leq 1 \), generally \( P \) is 0.5.

(3) Calculation of correlation degree

Correlation degree formula:

\[ r_{ij} = \frac{1}{n} \sum_{k=1}^{n} \xi_{ij}(k) \]  

3. Case study

Lupu Town is located in the middle of Yuhuan County, bordering Longxi Town in the east, Yucheng Street in the south, Yueqing Bay in the west, and Xuanmen Bay in the north. According to the overall plan of the county, Lupu Town is an important part of the northern district of Yuhuan Port. It is close to yuhuan New Town, the center of the district. It is 6 kilometers away from the central district of the county, and it is mainly connected with other towns and villages through 76 provincial road. There are 17 main rivers in the Lupu River system, with a total length of 29.63 kilometers and a basin area of 16.0 square kilometers. The drainage network is independent in distribution, including five independent water systems, namely, Xitang River system, Dongtang River system, Geling River system, Daotou River system and Hongshatang River system. The built area of Lupu belongs to Xitang River system. A total of 22 water quality monitoring points were set in The Lupu river system to monitor multiple water quality indicators, such as COD, and ammonia nitrogen, for the purpose of assessing the dynamic changes of water environmental quality.

3.1 Single factor evaluation method:

As showing from the figure above, the main pollutants exceeding the standard in Lupu Town, Yuhuan City from January to May 2009 were NH₃-N and TP. January ~ May COD Mn were not overweight, conform to the surface water environment IV class water standard. Except in March, NH₃-N exceeded the standard to varying degrees in January, February, April, and May, among which the stations 10, 13, 16 and 19 had the largest multiple of exceeding the standard. TP in January to May have exceeded the situation, site 9, 10, 19, 20 exceeding the situation is the most serious. The monthly variation chart of single factor index of three pollution factors from January to May is summarized. From January to May, the pollution at stations 10 and 19 was the most serious, with both NH₃-N and TP exceeding the standards.

3.2 Evaluation results of traditional Nemerow index method

According to the national surface water environment quality standard IV class water standard, calculated for each site within the tradition of Nemerow index and water quality categories. The result shown that before the water quality category is III, IV class more, most sites meet IV class water standards, only a few for V, bad V class water. January Site 9, 13, 16, 19 to bad V class water, site 10 for V class water, the rest of the sites meet the IV class water standard. February site 2 for V class water, site 10, 16, 20 for the bad V class water, the others all meet IV class water standard.
10 for V class water, site 19 to the worse V class water. April Site 10, 13, 14, 16 for V class water, site 19 to the V class water, the others all meet IV class water standard. May Site 1, 5, 14 for V class water, site 10, 11, 13, 19 for the bad V class water. Except for IV class water in February, the water quality at station 19 was the worst, the other four month for worse V class water, 18 water quality, the best site for class II or III class water.

3.3 Improve nemerow index evaluation method
Using Improve nemerow index evaluation method, we reevaluated the data. The results suggested that before the water quality category is II, III class water more, only a handful of sites do not satisfy the standard of class IV class water, water quality is good, the site 4 and 18 are II class water, site 19 of water quality is poorer, except for IV class water in February, the other 4 months for bad V class water. After the governance, water quality categories for more III class, most of the sites meet IV class water standard. But site 9 and 13 water quality is poorer, were higher than IV class water standard.

3.4 Grey relational degree analysis of water quality index
The grey relational degree analysis of water quality indexes can intuitively show the monthly changes of water quality in the study area. From the table above, you can see that engineering II class before class mostly in the water, only a few sites of water quality categories above II class water. Only January site 19 for V class water, the others all meet IV category criteria. February in addition to the site 10 for V class water, the others all meet IV class water standard. March, April and May, in addition to the site 19 for V class water, the others all meet IV class water standard. We know from the above that, site 19 except for III class water in February, the rest of the month are V class water. The water quality at the 10 site was also poor, the water quality types from January to May are respectively III, V, IV, IV, IV class. After engineering, September in addition to the site 7 and 9 for V class water, the others all meet IV class water standard. The calculation of grey correlation analysis is to obtain the correlation coefficient by calculating the maximum and minimum values. The better the water environment quality is, the higher the evaluation result will be, and the lower the evaluation result will be.

4. Conclusion
The types of water quality determined by different evaluation methods are different. Because of NH$_3$N and TP content exceeds standard, when using the single factor evaluation method for water quality analysis, often rely on the content of NH$_3$N and TP and ignore other pollution factors, the NH$_3$N and TP in water quality evaluation results play a leading role. The evaluation result of single factor evaluation method is lower than that of other water quality evaluation methods. The main reason is that this method takes the worst evaluation grade among all evaluation factors as the water quality category and weakens other water quality indicators. The secondary reason is that some of the water quality impact factors exceed the standard. This method plays a very important role in ensuring the evaluation of water safety, but it can only reflect the pollution status of a single factor, and cannot comprehensively reflect the quality status of water, and its evaluation results show over-protection. Therefore, this method is suitable for the evaluation of water quality with high requirements for water quality, as well as the evaluation of the main pollutants and the situation of the pollutants exceeding the standard.

In the practical application, the traditional Nemerow index method only considers the arithmetic mean value and maximum value, but does not consider the weight of pollution factors, etc., which results in the failure of the evaluation results to truly reflect the quality of environmental factors$^{[39]}$. The improved Nemerow pollution index method takes into account the weight of each evaluation factor, overcomes the shortcoming of the traditional Nemerow pollution index method that overemphasizes the role of the evaluation factor with high pollution concentration and fails to consider the weight of each evaluation factor, and more objectively reflects the river water quality status. However, this method is still limited to the evaluation of river water quality grade$^{[40]}$. The Nemerow
pollution index method is simple to operate, but the demarcation of water quality grade is subjective to some extent, which is suitable for intuitive and quick judgment of the state of water quality exceeding standards.

The water quality evaluated by grey relational degree analysis is the best, basic types of II class water, but there are a few V class water. The weight of each pollution index is distributed equally by grey relational degree analysis method, and the comprehensive effect of each pollution factor is fully considered. However, different pollution factors have different degrees of damage to water bodies, and the average distribution of proportional weight is unreasonable. This analysis method pays attention to the greyness of environmental system and not only reflects the correlation and fuzzy membership relationship between the monitoring sequence and the water quality standard sequence, but also has the advantages of simple principle, rigorous mathematical reasoning, clear concept, and reliable evaluation results, so it is not easy to be inconsistent with the actual situation. However, this method also has its limitations. For example, it cannot clearly judge the main pollution factors. Affected by the two-level difference of correlation coefficient, the evaluation value tends to be homogeneous and the resolution is low.

Compared with the three methods, because of the high concentration of ammonia nitrogen and total phosphorus in the study area and the existence of extreme values, the single factor evaluation method and nemerow pollution index method are not suitable. However, grey correlation analysis is not restricted by extreme values, so the evaluation results are more reasonable and reliable, and the changes of water quality before and after water environment treatment can be clearly seen. Different analytical methods have their own advantages. Different quantitative and qualitative methods can be used to analyze water quality and its pollution characteristics more comprehensively.

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