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Water Quality Assessment of Zhaitou River in Maoming City Based on Mathematical Model Analysis

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Abstract
This study aims to provide a novel combined of inspection method to realize the water quality characteristics of rivers entering the sea in Maoming City, thereby taking the Zhaitou River as the research area, using the water quality monitoring data from June to December 2021, and four influencing factors COD_{Mn}, NH3-N, DO and TN are selected. Then, the water quality is evaluated by using Fuzzy comprehensive evaluation method and Grey prediction GM (1,1) model, and the water quality in the next three phases is predicted. The results show that the Fuzzy comprehensive analysis indicated that the overall water quality from June to December 2021 belongs to class III water, especially the water quality in July and December is the worst, which are class IV and class V water respectively. According to the prediction of the Grey prediction model, the accuracy of the posterior error ratio is 0.114 at the lowest and 0.369 at the highest. Through the accuracy test, the relative residual of the four factors is within 20%, and the model fitting effect is good. The simulation prediction results show that the predicted values of the other three factors are rising except NH3-N.

Keywords: *Water quality assessment; Fuzzy comprehensive evaluation method; Grey prediction GM (1,1) model*

1. Introduction

In recent years, the quality of the water environment in the coastal waters of Maoming City has been polluted by land-based domestic sewage, agricultural wastewater, and industrial wastewater. In 2016, the Zhaitou River was listed as the key rectification object by the central environmental protection supervision group and provinces and cities due to its long-term inferior V level of surface water. Based on this, it is necessary to conform to the overall urban planning of Maoming (2011-2025), implement the concept of green ecology (Li and Nan, 2015), promote the construction of ecological civilization, maintain the health of rivers and improve the water management system. China has gradually established a relatively mature working mechanism for the prevention and control of water pollution (Geng et al., 2006). At present, the evaluation methods of water quality of rivers entering the sea in China are mainly based on the single factor index method and Nemerow index method (Cao et al., 2017; Li and Cui, 2012). However, due to the comprehensive influence of various factors on water quality and the different influences of different types of pollutants on water quality, it is easy to produce different or uncertain factors in the evaluation, and the fuzzy comprehensive evaluation method can better reflect the comprehensive quality of water (Dong et al., 2021).

In this paper, the fuzzy comprehensive evaluation method is used to evaluate the water quality based on the monitoring data of Zhaitou River in Maoming City from June to December 2021, and the grey prediction GM (1,1) model is used to predict the water quality. According to the comprehensive evaluation and prediction results, the corresponding improvement suggestions are given.

2. Study Area and Methodology

Study Area

Zhaitou River is located in Dianbai District, Maoming City, Guangdong Province. Its topography tilted from northeast to southwest. Its landforms are plains, terraces, and mountains. Rivers are widely distributed on the plain near the sea (show as Figure 1), and the Zhaitou river of the study area flows into Shuidong Bay from north to south. The plain is located in the low latitude area in the south of the northern regression line, belonging to the subtropical monsoon climate. The climate is warm all year round, and the rainfall is abundant. The average temperature is 23 °C, the hottest month is July, and the coldest month is January. The average annual rainfall is 1990.9 mm, with significant interannual variations. The easterly and southeasterly winds prevail in the area. The Shuidong Bay is a kind of national opening port, which has brought great changes to economic and social development and opened up a new channel for freight transport along the coast of Maoming.

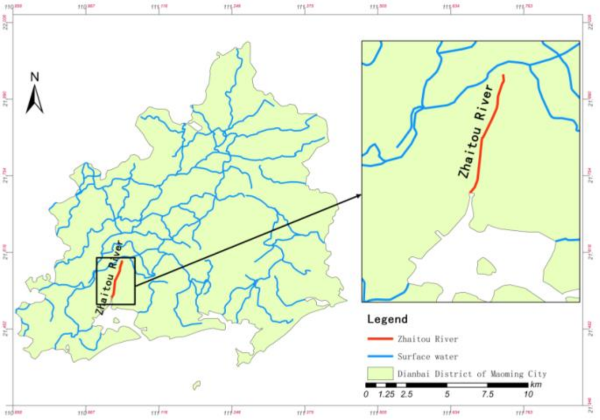

Figure 1 Map of Zhaitou River location in Dianbai District of Maoming City

Data sources and evaluation factors/standards

The sample data of this study were obtained from the environmental quality and detection data of Guangdong Provincial Department of Ecological Environment, and the "detection information of rivers entering the sea in Guangdong Province in the third and fourth quarters of 2021" was collected. Among them, COD_{Mn} (Chemical Oxygen Demand), NH_3-N (ammonia nitrogen content index), DO (Dissolved Oxygen) and TN (Total Nitrogen) were selected as the evaluation factors, show as Table 1. In addition, the "Surface water environmental quality standards (GB3838-2002)" as the evaluation standard, show as Table 2.

Table 1 Detection data of the estuary section of Zhaitou River (mg/L).

(**Source: The** rivers entering the sea in Guangdong Province in the third and fourth quarters of 2021**)**

month	COD_{Mn}	NH_3-N	DO	TN
July	7.400	1.090	5.500	6.110
August	2.600	0.940	5.200	1.000
September	4.500	0.940	5.800	3.390
October	5.300	0.520	6.200	2.970
November	5.500	0.560	5.600	3.400
December	5.000	0.450	6.700	5.600

Table 2 Environmental Quality Standards for Surface Water(GB3838-2002) (mg/L)

Water quality classification	Class I	Class II	Class III	Class IV	Class V
COD_{Mn}	≤2.00	≤4.00	≤6.00	≤10.00	≤15.00
NH_3-N	≤0.15	≤0.50	≤1.00	≤1.50	≤2.00
DO	≥7.50	≥6.00	≥5.00	≥3.00	≥2.00
TN	≤0.20	≤0.50	≤1.00	≤1.50	≤2.00

According to the statistical data of environmental quality and monitoring of Guangdong Provincial Department of Ecology and Environment, the detection data of COD_{Mn}, NH_3-N, DO and TN were collected, and the change trend of four evaluation factors of COD_{Mn}, NH_3 -N, DO and TN from July to December 2021 was plotted (show as Figure 2). The chart shows that COD_{Mn} is 7.4 mg/L in July and 5 mg/L in December. NH_3-N generally showed a decreasing trend, from 1.09 mg/L to 0.45 mg/L from July to December. The change trends of DO and TN were basically the same patterns, showing a trend of first decreasing and then increasing, and then decreasing and then increasing. From July to December, DO decreased from 5.5 mg/L to 5.2 mg/L, then increased to 6.2 mg/ L, and finally increased to 6.7 mg/L. TN decreased from 6.11 mg/L to 1 mg/ L, then increased to 3.39 mg/ L, and finally increased to 5.6 mg /L. Among the four evaluation factors, TN had the largest variation and NH_3-N was the most stable.

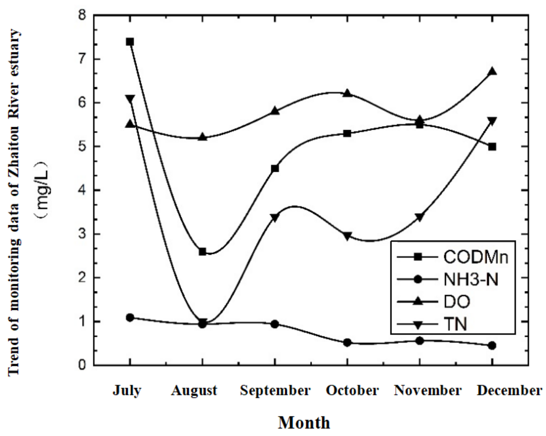

Figure 2 Trend of monitoring data of Zhaitou River estuary

(Source: Drawing by this study).

Study Methods

Through the research and investigation of the literature, the study found that scholars usually use a single fuzzy comprehensive evaluation method to evaluate the water quality, or use a single gray prediction model to predict the impact of environmental factors on the future water environment quality is the largest. However, there are few scholars who combine the two to evaluate the water quality, and there are few related literature. This paper will first evaluate the water quality of the Zhaitou River in Maoming City in the third and fourth quarters of 2021 by combining the fuzzy comprehensive evaluation method and the gray prediction model. On this basis, predicting the water quality in the next three periods, namely January, February, and March 2022, and can clearly reflect which factor or factors have the greatest impact on the water environment pollution. It is helpful to provide effective information for professionals who improve the water environment to degrade one or more of these factors in a more targeted way, while other factors that have an increasing trend of impact on the water environment can be continuously controlled and maintained through relevant technologies. The research technology roadmap of this paper is as follows (show as Figure 3).

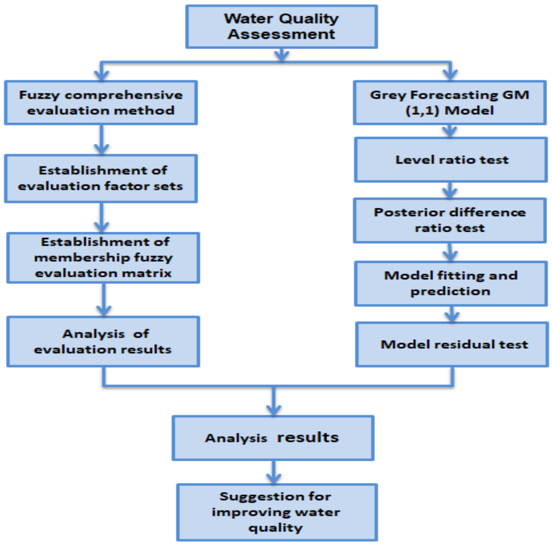

Figure 3 Technology Roadmap of this study

3. Fuzzy Comprehensive Evaluation Method

There are many uncertain factors in the comprehensive evaluation of water quality grades. Fuzzy comprehensive evaluation is a model theory and method based on fuzzy mathematics modeling, which can quantitatively analyze the influence of various indicators. Thereby to effectively solve the unreasonable phenomena of various limit states in the evaluation process, and ensure the objectivity and accuracy of the results. It is an effective quantitative method (Yang et al., 2016).

Establishment of evaluation factor sets

First of all, the evaluation factor set of water quality is established, such as U = {COD_{Mn}, NH_3-N, DO, TN}. Then according to the grade of "Surface Water Environmental Quality Standard" (GB 3838—2002), the evaluation grade set V = {I, II, III, IV, V} is determined, and the pollution degree is clean, unpolluted, light pollution, medium pollution, and heavy pollution respectively (Ma and Qiu, 2019; Qiang et al.,2020; Liang, 2021).

Establishment of membership fuzzy evaluation matrix

Secondly, the membership degree is determined and a fuzzy evaluation matrix is established. The membership degree is the quantitative indicators for differentiation and establishment of subordination to the evaluation set, that is, the degree to which each evaluation factor belongs to a certain water quality category. This study, according to the Surface Water Environmental Quality Standard, thus the membership function of evaluation factors to the evaluation set is established, then the membership degree of each evaluation factor is calculated, and the fuzzy evaluation matrix of membership degree is established such as equation (1) (Zhai et al., 2021).

$$R = R_{ij} = \begin{matrix} r_{21} & r_{22} & \cdots & r_{2j} \\ \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots \\ r_{i1} & r_{n2} & \cdots & r_{ij} \end{matrix} \quad (1)$$

Equation (1): where R_{ij} is the membership degree of monitoring factor i to water quality of category j, that is, the possibility of factor i being judged as water quality of category j. The weight set is established to represent the contribution of the factor to water pollution.

For the type with smaller monitoring index value and better water quality, the calculation formula of factor weight value is $w_i = x_i/S_i$, x_i is the measured value of this factor, and S_i is the average value of the grade limit of quality standard. That is $S_i = \Sigma S_{i,j}/5$. For the type with larger monitoring index value and better water quality, $w_i = S_i/x_i$ is taken to obtain the weight set W = (w_1, w_2,... w_i,... w_n). The weight coefficient set A= (a_1, a_2,..., a_n) is obtained by normalizing W with $a_i = w_i/\Sigma w_i$.

The results of fuzzy comprehensive evaluation of water quality are studied by using weighted average M (*,+) operator, Y= AxR= (a_1, a_2,..., a_i,..., a_n) × [R_{ij}]= (y_1, y_2,..., Y_i,..., y_n). According to the principle of maximum membership degree, producing a grade is taken as the evaluation result of the water quality grade of the monitoring station, and the water quality grade Y = max (Y_i) (Xia and Huo, 2020). When there are two or more maximum membership degrees, the water quality level close to the second maximum is selected as the final water quality level of the section.

Analysis and evaluation results

This study, according to the fuzzy comprehensive rating method, based on the normalized weight matrix and relative membership matrix of each factor from July to December of the river, the weights of water quality standards of I, II, III, IV, and V types per month (show as Table 3) and the fuzzy comprehensive evaluation results of water quality per month (show as Table 4) were calculated.

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Table 3 Weights of each evaluation index

section	Monitor the month	Evaluation metric weights				
		Class I	Class II	Class III	Class IV	Class V
Zhaitou River estuary	July	0.122	0.141	0.183	0.320	0.233
	August	0.112	0.047	0.357	0.270	0.214
	September	0.093	0.108	0.321	0.250	0.228
	October	0.112	0.224	0.317	0.128	0.219
	November	0.050	0.187	0.328	0.271	0.119
	December	0.049	0.094	0.227	0.296	0.334

Table 4 Fuzzy comprehensive evaluation results

section	Monitor the month	Water quality category	Degree of contamination
Zhaitou River estuary	July	Class IV	Medium pollution
	August	Class III	Light contamination
	September	Class III	Light contamination
	October	Class III	Light contamination
	November	Class III	Light contamination
	December	Class V	Heavy contamination

According to the weight results of each evaluation index, taking Zhaitou River in July 2021 as an example, the weight values of five evaluation grades are 0.122, 0.141, 0.183, 0.320, and 0.233, respectively. The weight value of Class IV in the five evaluation grades is the highest (0.320). Combined with the maximum membership rule, the final comprehensive evaluation result is “V”. Similarly, water quality categories from August to December are available. By June to December 2021, the water quality of the river was mostly Class III, and concentrated from August to November, with light pollution. In July and December, the water quality was Class IV and Class V, respectively, and the water quality was poor, belonging to medium pollution and heavy pollution, respectively. The water quality evaluation results of each month section are shown in Table 4.

In addition, the results of the fuzzy comprehensive evaluation of the cross-sections in each month show that the water quality of the Zhaitou River estuary is mainly in the light pollution state, and only in December is the heavy pollution. The reason for the relatively poor water quality of the Zhaitou River may be domestic sewage and industrial wastewater from land-based towns.

4. Grey Forecasting GM (1,1) Model

The grey prediction model can effectively predict the data series with very small number (for example, only 4: COD_{Mn}, NH_3-N, DO, TN) and low data integrity and reliability. It uses differential equations to fully mine the essence of the data, the modeling needs less information, the error is relatively small, the prediction accuracy is relatively high, the credibility is strong (Zhao and Lin,2021), and it does not need to consider the distribution law or change trend and so on. The grey prediction GM (1,1) model is expressed by differential equation, which reflects the influence of environmental factors on environmental quality. Grey prediction based on the concept of grey module is to deal with the irregular original data according to a specific method to turn it into more regular time series data, and then establish a model (Chen, 2017). Thus, the correct description and effective monitoring of the evolution law of the system can be realized, and it has the advantage of making full use of "less data" and "small samples" for prediction (Wang and Wang, 2013; Lai and Zhou, 2013; Wei et al., 2013).

Data inspection and processing

GM (1,1) model construction has four steps such as follows:

The first step: Level ratio test;

The second step: Posterior difference ratio test;

The third step: Model fitting and prediction;

Step 4: Model residual test.

Ratio test

In order to ensure the feasibility of GM (1,1) modeling method, it is necessary to do the necessary test and processing for the known data (Yang and Wei,2020). The purpose of this step is whether the data sequence has a suitable regularity and whether a satisfactory model can be obtained. This step is only a preliminary test, and the significance is relatively small. Let the original data be listed as $x^{(0)} = (x^{(0)}(1), x^{(0)}(2),..., x^{(0)}(n))$, and calculate the sequence ratio

$$\lambda(k)=x^{(0)}(k-1)/x^{(0)}(k),\ k=2,3,...,n \quad (2)$$

If all the level ratios fall within the allowable coverage interval (e ^(-2/(n+1),e^ (2/n+1)) where e is the natural logarithm and n is the sample size of the analysis), then the sequence $x^{(0)}$can establish the GM(1,1) model and conduct grey prediction. Otherwise, do the appropriate data transformation processing, such as translation transformation:

$y^{(0)}(k)=x^{(0)}(k)+c, k=1,2,...,n$ (3)

Establishment of GM (1,1) model and posterior error ratio test

To establish GM (1,1) model, let $x^{(0)}=(x^{(0)}(1),x^{(0)}(2)...,x^{(0)}(n))$ meet the above requirements.

$x^{(0)}(k)+ az^{(1)}(k)=b$ (4)

In the formula, a is called development coefficient, and b is grey action quantity. The estimated values of a and b are obtained by regression analysis, so the corresponding albino model is

$Dx^{(1)}(t)/dt + ax^{(1)}(t)= b$ (5)

The albino differential equations also called shadow equations, where a and b are constants. The solution to the differential equation (called the time response function) is

$x^{(1)}(t)=(x^{(0)}(1)-b/a)e^{-a(t-1)}+b/a$ (6)

So the predicted value is

$\hat{x}(1)(k+1)=(x(^{0)}(1)-b/a)e^{-ak}+b/a, k=1,2,...,n-1$ (7)

This is the prediction formula for the number sequence. Since this is the prediction value of the number sequence generated by accumulation, it can obtain the restored prediction value of the original number sequence through the accumulation and subtraction process: The predicted values are obtained accordingly:

$\hat{x}^{(0)}(k+1)=\hat{x}^{(1)}(k+1)-\hat{x}^{(1)}(k), k=1,2,...,n-1$ (8)

After building the model, the posterior error ratio C value is obtained, which is residual variance/data variance. It is used to measure the fitting accuracy of the model, the smaller the C value is, the better, generally less than 0.65. The accuracy verification results are shown in Table 5.

Table 5 Model fit accuracy verification table

Evaluation factors	Development factor a	Gray effect b	Posterior difference ratio C value	precision
COD_{Mn}	-0.029	17.558	0.181	High precision（C＜0.35）
NH_3-N	0.051	3.196	0.114	High precision（C＜0.35）
DO	-0.047	4.966	0.369	Accuracy Pass（0.35＜C＜0.5）
TN	-0.041	19.001	0.127	High precision（C＜0.35）

Table 5 shows the development coefficient (a), grey effect (b), and posterior difference ratio (C). Which relations such as follows: Grey prediction model that can be constructed by development coefficient and grey action. The development coefficient represents the development law and trend of the series, and the grey effect reflects the changing relationship of the series. The posterior difference ratio can verify the accuracy of grey prediction. The smaller the posterior difference ratio is, the higher the accuracy of grey prediction is.

Generally, the model accuracy is high if the posterior error ratio C value is less than 0.35. If the C value is less than 0.5, the model accuracy is qualified. If the C value is less than 0.65, the model accuracy is basically qualified. If the C value is greater than 0.65, the model accuracy is unqualified.

The grey prediction model fitting accuracy verification table shows that the posterior error ratios of COD_{Mn}, NH_3-N, DO and TN are 0.181, 0.114, 0.369, and 0.127, respectively. Except the posterior error ratio of DO factor is between 0.35 and 0.5 which showing that the accuracy of the model is qualified, and the posterior error ratios of the rest three factors are less than 0.35, indicating that the model has high accuracy. In summary, the grey prediction accuracy of COD_{Mn}, NH_3-N, DO and TN is better, which can be directly predicted and analyzed.

Simulation fitting and prediction results

After building the model, the fitting value of the model and the predicted value of the last three periods are obtained. The simulation fitting results of each evaluation factor and the simulation prediction results of the next three periods are shown in Table 6 and Table 7, respectively.

Table 6 Simulation fitting results table

Month	COD_{Mn}			NH_3-N			DO			TN		
	The original value	Predicted values	Residuals	The original value	Predicted values	Residuals	The original value	The original value	Residuals	The original value	Predicted values	Residuals
Jul.	7.400	7.400	0	1.090	1.090	0	5.500	5.500	0	6.110	6.110	0

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Aug.	2.600	3.468	-0.868	0.940	0.962	-0.022	5.200	5.353	-0.153	1.000	1.463	-0.463
Sept.	4.500	4.008	0.492	0.940	0.815	0.125	5.800	5.613	0.187	3.390	2.328	1.062
Oct.	5.300	4.563	0.737	0.520	0.674	-0.154	6.200	5.886	0.314	2.970	3.230	-0.260
Jan.	5.500	5.135	0.365	0.560	0.541	0.019	5.600	6.171	-0.571	3.400	4.170	-0.770
Feb.	5.000	5.724	-0.724	0.450	0.415	0.035	6.700	6.471	0.228	5.600	5.150	0.450

Table 7 Forecast results of the next 2 periods

Forecast time	Predicted values（mg/L）			
	COD_{Mn}	NH_3-N	DO	TN
January 2022	6.329	0.294	6.785	6.171
February 2022	6.952	0.179	7.115	7.236
March 2022	7.594	0.071	7.461	8.346

As can be seen from Table 7, from January 2022 to March 2022, the forecast index of COD_{Mn}, DO and TN showed an upward trend, while that of NH_3-N decreased. According to the curve fitting and prediction results of GM (1,1) model, it is estimated that by March 2022, the index of COD_{Mn}, DO and TN will increase by 51.88%, 11.35%, and 48.21% respectively compared with December 2021, and decrease by 84.22% compared with December 2021.

It shows that the COD_{Mn} in the water environment of the third stage of the Zhaitou River will tend to Class IV, NH_3-N will tend to Class I, DO will tend to Class I, and TN will tend to Class V. The factors affecting the deterioration of the water quality of the Zhaitou River in the future are COD_{Mn} and TN, while the factors affecting the improvement of water quality are NH_3-N and DO. If the water quality of the Zhaitou River is to be improved as a whole, it is necessary to degrade COD_{Mn} and TN. The measured and predicted values of COD_{Mn}, NH_3-N, DO, and TN from July to December 2021 are shown in Figure 4, 5, 6, and 7, respectively.

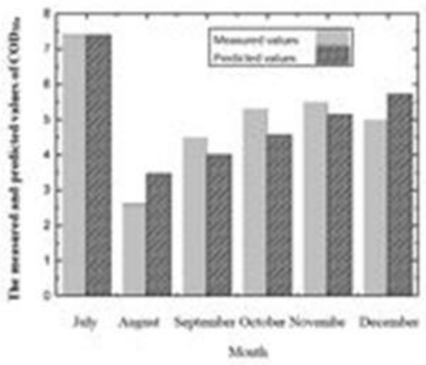

Figure 4 The measured and predicted values of COD_{Mn}

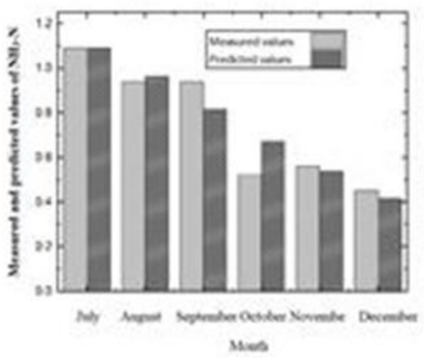

Figure 5 Measured and predicted values of NH_3-N

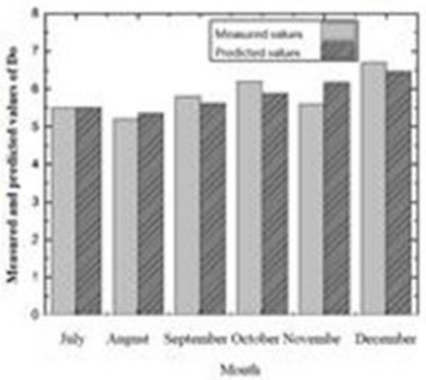

Figure 6 Measured and predicted values of Do

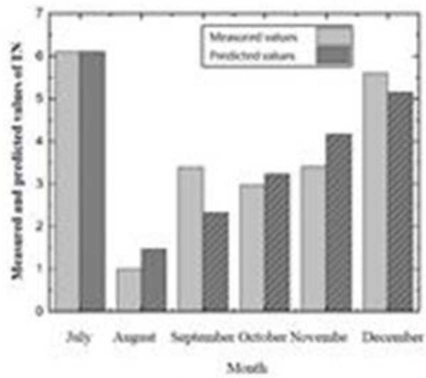

Figure 7 Measured and predicted values of TN

Model residual test: calculating relative residual

Model residual test is a post-multiple comparison method. In which mainly views the relative error value and grade deviation value. Relative error value = residual value absolute value / original value. The smaller the relative error is, the better it is. Generally, it is less than 20 %, indicating good fitting.

$$\varepsilon(k)=(x^{(0)}(k)-\hat{x}^{(0)}(k))/x^{(0)}(k),\ k=1,2,\ldots,n \qquad (9)$$

If all $|\varepsilon(k)| < 0.1$, it is considered to meet higher requirements; otherwise, if all $|\varepsilon(k)| < 0.2$, it is considered to meet the general requirements.

After calculating relative residuals, Table 8 shows the relative error table of the grey prediction model. The table shows that the average relative error of the COD_{Mn} model is 13.221 %, indicating that the model fitting effect is good. The NH_3-N model was 9.439 %, indicating that the model fitting effect was good. The DO model was 4.143 %, indicating that the model fitting effect was good. The TN model was 19.506 %, indicating that the model fitting effect was good. In summary, all the fitting of the models to COD_{Mn}, NH_3-N, DO and TN meet the requirements.

Table 8 Model relative errors

	COD_{Mn}	NH_3-N	DO	TN
relative error	13.221%	9.439%	4.143%	19.506%
Model fit (<20%)	good effect	good effect	good effect	good effect

5. Conclusion

This study aims to provide a novel combined of inspection method to realize the water quality of rivers entering the sea in Maoming City, thereby the Fuzzy comprehensive evaluation method and Grey prediction GM (1,1) model were selecting. The experiment proves that the combined application of these two methods is feasible and worth adopting.

Firstly, based on the water environmental monitoring data of the Zhaitou River estuary from July to December 2021, the fuzzy comprehensive evaluation method was used to carry out the water quality evaluation. Meanwhile, based on the concept of membership degree of weight, using the fuzzy comprehensive evaluation can effectively avoid the subjective influence of human beings in the water quality evaluation, so it can objectively and comprehensively reflect the water quality under the combined influence of multiple factors.

Secondly, by using the grey prediction model in the water quality prediction of Zhaitou River, the overall accuracy of each water quality index meets the requirements of simulation accuracy. The difference between the actual value and the predicted value from July to December 2021 is small, and the prediction results of grey prediction model for water quality are of high accuracy, good reliability, and high credibility of the simulation results. Therefore, it is feasible to use the grey prediction model to predict the water quality of the Zhaitou River, and this method can be used to obtain more accurate prediction data.

To the all, this study’s analysis results show that:

(1) Through the fuzzy comprehensive evaluation method, it is known that the monthly variation of water quality of the Zhaitou River is dominated by type III water body. The better water quality of the river is concentrated in August – November 2021, and the water quality of the month is type IV and type V, respectively. The water pollution degree shows light pollution due to heavy pollution. Compared with July 2021, there are two indicators (NH_3-N and DO) in December 2021, although they are improved, the overall water environment is still in a state of light pollution. The main reasons may be as follows: Farmland and villages are the main pollution sources around the Zhaitou River, and the main pollution sources are domestic sewage and aquaculture wastewater in the surrounding rural areas; Some sections of the river are polluted by industrial wastewater such as brick factories and concrete mixing plants; Many places of the river bed are seriously silted, garbage and high sediment content; The soft revetment of the river bank in the suburbs is loose, and the soil’s erosion is serious; The self-purification ability of the river is poor and the water quality is poor.

(2) The prediction results of grey prediction GM (1,1) model show that NH_3-N, which is seriously harmful to human health, has been paid attention to and controlled, and DO, the oxygen source of all aquatic organisms, has also been improved, which plays an important role in promoting aquaculture. However, the COD_{Mn} and TN indexes are still increasing, which will cause eutrophication of water bodies and water blooms, leading to the mad growth of aquatic algae. The decay of dead plants in water will consume DO and seriously lead to the death of aquatic organisms. Therefore, the water quality pollution factors in the next three periods are mainly COD_{Mn} and TN.

In the end, in view of the above fuzzy comprehensive water quality evaluation and the prediction of the grey GM (1,1) model for the water quality in the next three periods, some suggestions are put forward for improving the water quality of Zhaitou River; Such as the domestic sewage near the river is discharged by harmless treatment with industrial and agricultural wastewater; The river bottom must be cleared and silted, and the ecological enclosure of trash rack river have to constructed; The brick drainage ditch is set to prevent the further loss of topsoil; The underwater ecology, river water quality improvement and purification, and biological contact oxidation are constructed.

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