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Application of Entropy Fuzzy Comprehensive Evaluation in Water Quality Evaluation of the Mainstream of Haihe River in Tianjin

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Abstract

In 2019, Tianjin had an area of 23,087 hectares of freshwater aquaculture. Inland fishery waters are an important source of water for inland aquaculture in Tianjin, therefore, it is of great significance to protect the environment of inland fishery waters. Based on data of water quality collected from the mainstream of Haihe River in Tianjin from 2016 to 2020, the environmental quality was assessed using the fuzzy synthetic evaluating method. The results for the last 5 years showed that the water quality of mainstream of Haihe River fit for the surface water environment quality V standards in 2016. It was found out that the water has greatly improved during the five years. It achieved or was better than the surface water environment quality III in 2020, and even achieved Iin May. The water can meet the water requirements of fishery waters such as the fish and shrimp winter farm, the migration routes, and the aquaculture area, indicating that the water treatment work has achieved obvious results.

Keywords

The Mainstream of Haihe River, Fuzzy Synthetic Evaluating Method, Water Quality Assessment

1. Introduction

The Haihe River system includes five tributaries of Chaobai River, Yongding River, Daqing River, Ziya River and South Canal. The main stream of the Haihe River originated from the Sanchakou in Tianjin (Zhao et al., 2014), it crosses the Tianjin City, Dongli District, and Jinnan District to the east, and merges into the Bohai Sea at Tanggu, Binhai New District. The mainstream of Haihe River is the main drainage and flood control channel in Haihe River Basin, with a total length of 72km and an average width of about 100 m (Gong & Mei, 2017). After the com-

pletion of the Erdaozha, the main stream of Haihe River will be divided into upstream and downstream. The upstream water is freshwater, and the downstream water is affected by the tide, and the salinity changes greatly, thus forming two completely different water environments.

According to the 2020 *China Fishery Statistical Yearbook* (Fisheries Administration of the Ministry of Agriculture and Rural Affairs, National Fisheries Technology Extension Center, & China Society of Fisheries, 2020), in 2019, the freshwater aquaculture area of Tianjin was 23,087 hectares, of which the pond aquaculture area was 22,739 hectares, and the reservoir aquaculture was 220 hectares, the river gitch aquaculture area was 23 hectares, other 105 hectares. The inland fishery waters are an important source of water in Tianjin inland aquaculture, therefore, it is of great significance to protect the environment of inland fishery waters.

At present, there are many methods to evaluate the water environment, such as single factor evaluation method (Japan Machinery Industry Federation et al., 1987), the comprehensive index method (Zou et al., 1983), the fuzzy comprehensive evaluation method (Chen et al., 2011; Fan, 1998; Lin et al., 2003; Wang & Pan, 2010; Jiao et al., 2015), Nemerow index (Zheng, 2015; Chen, 2007), gray clustering method (Jiang et al., 2012; Wang et al., 2007), etc., and each evaluation method has its own advantages and insufficient. Based on the monitoring of the water quality of the mainstream of Haihe River from 2016 to 2020 in Tianjin, the use of entropy fuzzy comprehensive evaluation methods evaluated the water quality, in order to provide basic data for the protection of fishery ecological environment, to provide technical support for the enhancement release, and to improve water quality for the mainstream of Haihe River.

2. Sampling and Analysis Methods

2.1. Investigation Time and Scope

The study area was selected to be in the mainstream of the Haihe River, with a total of 3 monitoring stations and a monitoring water area of 330 hm^2. Each station was conducted in May, July, and September from 2016 to 2020. The latitude and longitude of the monitoring stations are listed in **Table 1**.

Table 1. The longitude and latitude of the station for the mainstream of Haihe River.

Station	Longitude	Latitude
Sanchakou	117˚11'19"	39˚8'40"
Waihuan River	117˚18'41"	39˚4'24"
Erdaozha upstream	117˚27'20"	39˚1'16"

2.2. Monitoring Items and Methods

Water quality monitoring items: permanganate index, total nitrogen, total phosphorus, petroleum, dissolved oxygen. The sample collection and testing methods were implemented in accordance with *The Specification for Ecological Environment Monitoring of Fisheries—Part 1*: *General Rules* (Ministry of Agriculture of

the People's Republic of China, 2007).

One water sample was taken at each station, with a sampling depth of 0.5 m, and arithmetic mean values were calculated from the three monitoring stations for each month.

2.3. Evaluation Method

The entropy weight fuzzy comprehensive evaluation method was used to analyze and evaluate the water quality status of the mainstream of Haihe River.

2.3.1. Establish Evaluation Factor

Assume that the fuzzy subset composed of the actual measurement concentration results of the m water quality indicators participating in the evaluation in the evaluation index was:

$U = \{x_1, x_2, x_3, \cdots, x_i, \cdots, x_m\}$, where x_i was the actual measurement result of the evaluation parameter i.

2.3.2. The Establishment of Fuzzy Evaluation Set

The evaluation set was a collection of all possible evaluation results for each evaluation object. The evaluation set of environmental quality was a collection of n water quality evaluation standard grades corresponding to m water quality indicators, which can be expressed as:

$V = \{V_1, V_2, \cdots, V_j, \cdots, V_n\}$, where V_j is the n evaluation standard grades of the evaluation parameter x_i.

According to the *Environmental Quality Standards for Surface Water* (State Environmental Protection Administration of China, 2002), the surface water quality was divided into five grades. Therefore, the evaluation set is determined to be S = {I, II, III, IV, V}. The environmental quality grade standards for surface water were in **Table 2**.

Table 2. Quality standard for surface water mg/L.

Evaluation grade	Dissolved oxygen	Permanganate index	Total nitrogen	Total phosphorus	Petroleum
I	7.5	2	0.2	0.02	0.05
II	6	4	0.5	0.1	0.05
III	5	6	1.0	0.2	0.05
IV	3	10	1.5	0.3	0.5
V	2	15	2.0	0.4	1.0

2.3.3. Establish Fuzzy Relationship Matrix

After both X and V were given, by evaluating each pollution index, the fuzzy relationship between each pollution index and each evaluation standard was obtained, thereby establishing a fuzzy relationship matrix R:

$$R = \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{20} \\ \vdots & \vdots & \vdots & \vdots \\ r_{m1} & r_{m2} & \cdots & r_{mn} \end{bmatrix} \quad (1)$$

In the formula: m is the number of evaluation factors, $i = 1, 2, \cdots, m$; n is the water grade, $j = 1, 2, \cdots, n$.

If the water environment quality index is better with a small distribution, its membership function adopts a small-scale distribution (such as COD_{Mn}, etc.), Dissolved oxygen is just on the contrary. Larger value is preferred, and big distribution is used.

The method of establishing the membership function of the concentration of each evaluation index for the partial small distribution is as follows:

The membership function of the *I*-level water corresponding to the *i*-th index can be expressed as:

$$r_{i1} = \begin{cases} 1 & x_{ik} \le c_{i1} \\ \dfrac{c_{i2} - x_{ik}}{c_{i2} - c_{i1}} & c_{i1} < x_{ik} \le c_{i2} \\ 0 & x_{ik} > c_{i2} \end{cases} \tag{2}$$

The membership function of the j-level water corresponding to the *i*-th index can be expressed as:

$$r_{ij} = \begin{cases} 0 & x_{ik} \le c_{i,j-1}, x_{ik} \ge c_{i,j+1} \\ \dfrac{x_{ik} - c_{i,j-1}}{c_{ij} - c_{i,j-1}} & c_{i,j-1} < x_{ik} \le c_{ij} \\ \dfrac{c_{i,j+1} - x_{ik}}{c_{i,j+1} - c_{ij}} & c_{ij} < x_{ik} < c_{i,j+1} \end{cases} \tag{3}$$

The membership function of the *n*-level water corresponding to the *i*-th index can be expressed as:

$$r_{im} = \begin{cases} 0 & x_{ik} \le c_{i,n-1} \\ \dfrac{x_{ik} - c_{i,n-1}}{c_{in} - c_{i,n-1}} & c_{i,n-1} < x_{ik} \le c_{in} \\ 1 & x_{ik} > c_{in} \end{cases} \tag{4}$$

r_{ij} represents the measured value of the environmental factor of the *i*-th pollutant, which can be judged as the possibility of the *j*-th level of water environmental quality level, that is, the degree of subordination of the *i*-th index to the *j*-grade water environmental quality standard.

2.3.4. Determination of Weight

If the evaluation index and evaluation object are m and n respectively, the original matrix can be formed as: $R' = \left(r'_{ij}\right) m \times n$.

$$R = \begin{bmatrix} r'_{11} & r'_{12} & \cdots & r'_{1n} \\ r'_{21} & r'_{22} & \cdots & r'_{20} \\ \vdots & \vdots & \vdots & \vdots \\ r'_{m1} & r'_{m2} & \cdots & r'_{mn} \end{bmatrix} \tag{5}$$

Standardize the data on the original matrix, and get:

$$R = \left(r_{ij}\right)_{m\times n}.$$

r_{ij} is the standard value of the j-th evaluation object on the evaluation index, $r_{ij} \in [0, 1]$. Among them, for the big distribution factors, and get:

$$r_{ij} = \frac{r'_{ij} - \min\left\{r'_{ij}\right\}}{\max\left\{r'_{ij}\right\} - \min\left\{r'_{ij}\right\}}; \tag{6}$$

For the small distribution factors, and get:

$$r_{ij} = \frac{\max\left\{r'_{ij}\right\} - r'_{ij}}{\max\left\{r'_{ij}\right\} - \min\left\{r'_{ij}\right\}}; \tag{7}$$

2.3.5. Determination of Entropy

In the evaluation system where the evaluation index and evaluation object are m and n respectively, the entropy of the i-th index is defined as:

$$H_i = -k\sum_{j=1}^{n} f_{ij} \ln f_{ij}, \tag{8}$$

In the formula: $i = 1, 2, \cdots, m$, $f_{ij} = \dfrac{r_{ij}}{\sum_{j=1}^{n} r_{ij}}$, $k = \dfrac{1}{\ln n}$, and suppose that in the formula: $f_{ij} = 0$, $f_{ij} \ln n = 0$.

2.3.6. The Definition of Entropy Weight

On the basis of the definition of entropy value, define the entropy weight of the i-th index, namely:

$$w_i = \frac{1 - H_i}{m - \sum_{i=1}^{m} H_i} \tag{9}$$

$$0 \le w_i \le 1, \quad \sum_{i=i}^{m} w_i = 1.$$

3. Results and Analysis

3.1. Water Quality Monitoring Results and Evaluation

The measured average values of the physical and chemical factors in May, July, and September from 2016 to 2020 are shown in Table 3.

Table 3. Mean value of the physical and chemical factors.

Year	Month	Dissolved oxygen	Permanganate index	Total nitrogen	Total phosphorus	Petroleum
		mg/L				
2016	May	8.83	13.4	2.87	0.175	0.102

Continued

2016	July	6.29	51.5	9.46	2.89	0.106
	September	5.15	15.5	5.45	0.637	0.139
2017	May	8.20	5.88	3.90	0.160	0.103
	July	8.99	11.0	2.61	0.267	0.0502
	September	2.25	6.49	2.56	0.170	0.0484
2018	May	8.27	8.16	1.89	0.0680	0.0860
	July	7.51	15.2	4.80	0.484	0.0491
	September	3.39	6.94	2.73	0.248	0.0712
2019	May	7.32	4.96	3.18	0.0653	0.0587
	July	5.32	7.91	2.00	0.0883	0.0807
	September	8.46	17.1	4.50	0.160	0.0400
2020	May	8.08	10.8	1.20	0.0653	0.0284
	July	4.94	8.83	1.58	0.0830	0.0373
	September	5.82	12.7	3.86	0.0633	0.0267

3.2. Evaluation Results of the Physical and Chemical Factors

The fuzzy relationship matrix R represents the membership degree of the actual measured value of each factor to each grade of water quality. For example, the water quality matrix of the mainstream of Haihe River in May 2016 is as follows:

$$R_{2016-05} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.32 & 0.68 \\ 0 & 0 & 0 & 0 & 1 \\ 0 & 0.25 & 0.75 & 0 & 0 \\ 0 & 0 & 0.884 & 0.116 & 0 \end{bmatrix} \tag{10}$$

Follow the same method to establish other fuzzy relationship matrix, and this paper will not list them one by one here.

Table 4. The entropy weight of every evaluation index.

Station	Dissolved oxygen	Permanganate index	Total nitrogen	Total phosphorus	Petroleum
Entropy weight	0.25	0.18	0.20	0.19	0.18

The fuzzy relationship matrix and the entropy weight are combined to obtain the fuzzy comprehensive evaluation set of each evaluation object, which is defined as the following formula:

$$K = W \cdot R . \tag{11}$$

In the formula, K is the result of fuzzy comprehensive evaluation; W is the entropy weight obtained from Table 4; R is the fuzzy relationship matrix obtained from (10).

Table 5 shows the fuzzy comprehensive evaluation results of the water quality monitoring in the mainstream of Haihe River from 2016 to 2020.

Table 5. Results of the fuzzy synthetic evaluation.

Year	Month	The degree of membership					grade
		I	II	III	IV	V	
2016	May	0.250	0.0475	0.302	0.0785	0.322	V
	July	0.0482	0.249	0.302	0.0785	0.322	V
	September	0	0.0375	0.357	0.0356	0.570	V
2017	May	0.200	0.0920	0.484	0.0236	0.200	III
	July	0.200	0	0.266	0.295	0.239	IV
	September	0.200	0.0600	0.316	0.0244	0.400	V
2018	May	0.270	0.120	0.299	0.163	0.148	III
	July	0.420	0	0	0	0.580	V
	September	0	0	0.470	0.266	0.264	III
2019	May	0.259	0.230	0.297	0.00399	0.210	III
	July	0.0285	0.226	0.431	0.105	0.210	III
	September	0.410	0.0770	0.113	0	0.400	I
2020	May	0.509	0.101	0.108	0.241	0.0308	I
	July	0.218	0.142	0.301	0.300	0.0288	III
	September	0.263	0.302	0.0450	0.0932	0.287	II

4. Discussion and Conclusion

Water quality grades in this study represent in-situ conditions at individual monitoring stations with no spatial averaging. Entropy weights were calculated using the full 2016-2020 dataset across all stations and months to quantify long-term factor importance rather than seasonal variability. Fuzzy comprehensive evaluation indicates the Haihe mainstream stayed at Grade V in all three months of 2016, followed by progressive improvement after 2017. It reached Grade III in May, Grade IV in July and Grade V in September 2017; Grade III in May/September and Grade V in July 2018, when extreme rainfall induced severe non-point pollution. In 2019, values were Grade III (May, July) and Grade I (September). 2020 saw Grade I in May, Grade III in July and Grade II in September. Under GB 3838-2002, Grade III water fits drinking water source secondary protection zones, fish migration/overwintering grounds and aquaculture. The five-year record confirms an overall improving trend; by 2020, water quality met or exceeded Grade III (Grade I in May), satisfying fishery water needs.

Multiple pollutant sources affect the mainstream. As a flood channel, it receives urban combined storm-sewage and illicit industrial/domestic discharges, forming contaminated sediment and internal pollution. Tianjin's water shortage leads to farmland wastewater irrigation, while replenishment tributaries carry domestic

sewage, introducing pollutants during water diversion. Shipping, tourism and waste add further pollution. Marked seasonal variation exists: July water quality is worse than May and September. Summer warming fuels algal blooms and lowers dissolved oxygen, and flood rainfall flushes mixed sewage into the river, aggravating deterioration.

Tianjin launched mainstream dredging in 2003. Recent source control and routine aquatic plant salvage support pollution regulation. Fisheries authorities have stocked silver carp and bighead carp fry annually since 2004 to restore fishery resources. The *Haihe River Basin* (*Tianjin*) *Aquatic Biodiversity Conservation Plan* was released in 2017 to conserve aquatic germplasm resources. Five-year comparisons show prominent water quality gains in the Tianjin reach, validating the success of water environment management.

From 2016 to 2020, classification results show sustained water quality improvement in the Haihe mainstream, with grades upgrading from Grade V to I-III to satisfy fishery habitat requirements. A distinct seasonal pattern exists: flood-season (July) water quality is poorer than dry-season (May, September), driven by non-point pollutant flushing and biological oxygen consumption. This seasonal feature informs fishery water management. We propose strengthened pre-flood pollutant discharge control, coupled with intensified real-time monitoring and early warnings in July to safeguard aquatic habitats and fishery resources.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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