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Original scientific paper

Comparative Water Quality Evaluation of Fu River Using Multiple Methods

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Abstract: This study evaluated and compared three water quality assessment methods: Canadian Water Quality Index (CWQI), Weighted Euclidean Distance (WED), and Fuzzy Comprehensive Evaluation (FCE) to analyze the water quality of the Fu River in Baoding City, China. Water samples were collected from 19 monitoring sections along the river in 2018 and tested for pH, turbidity, dissolved oxygen, chemical oxygen demand (COD), ammonia nitrogen, and total phosphorus. The CWQI method provided relatively simple water quality rankings. In contrast, the WED and FCE methods incorporated fuzzy mathematical principles to produce more nuanced, multi-dimensional water quality assessments. All three methods indicated serious eutrophication and poor water quality in the Fu River, with ammonia nitrogen and total phosphorus as the primary pollution factors. The FCE method offered the most hierarchical and objective evaluation results. This comparative study demonstrates that employing multiple water quality evaluation techniques can produce more robust and holistic insights into river water quality. The findings provide valuable guidance for selecting site-specific water assessment methods.

Keywords: Canadian water quality index act; Fu River; fuzzy comprehensive evaluation method; water quality evaluation; weighted Euclidean distance method

1 INTRODUCTION

The evaluation and analysis of river water quality can not only effectively develop and utilise surface water resources but also have positive significance for water resources protection and economic development. Appropriate water quality evaluation methods are crucial for developing and protecting water resources [1]. At present, there are many water quality evaluation methods, including comprehensive pollution index method, Nemerow index method, fuzzy comprehensive analysis method, principal component analysis method, Gray clustering method, etc. [2-10]. The above methods have their own advantages and disadvantages, and different analysis methods may produce different results. Therefore, it is very important to select appropriate methods for water quality analysis and evaluation in different river sections.

The Canadian Water Quality index method analyses the water quality in the study area from three aspects: scope, amplitude and frequency, and the evaluation results are concise and intuitive [11-16]. The fuzzy comprehensive evaluation method considers all evaluation factors and assigns weight to each pollution factor. In the actual application process, it has been proved that the evaluation results are objective and this method can comprehensively analyse water quality through multiple factors [17-19]. Weighted Euclidean distance method is an approach improved on the basis of the weighted Euclidean distance model, which is suitable for water quality evaluation [20, 21]. In the recent applications, the evaluation results of the weighted Euclidean distance method, fuzzy comprehensive evaluation method and grey clustering method were compared and analysed, which verified the scientificity and rationality of the weighted Euclidean distance method [22, 23].

The water quality of Baoding downtown section of Fu River is evaluated and comparatively analysed using the Canadian water quality index method, the weighted Euclidean distance method and the fuzzy comprehensive evaluation method, aiming to learn the water quality of Baoding downtown section of Fu River in the monitoring period and select the method suitable for analysing the water quality of Baoding downtown section of Fu River through comparing the adaptability and reliability of the three different methods, thus providing more scientific reference for the protection and management of the water quality of Fu River.

2 METHODS AND MATERIALS

2.1 Overview of the Study Area

The whole Fu River is originally located within Baoding City. Today, its upstream is located in Baoding City, while the downstream is located in Xiong'an New Area. The original mainstream of the Fu River is the Yimuquan River, which is one of the southern tributaries of the Daqing River in the Haihe River Basin. The study area is the downtown section of Fu River in Baoding City. A total of 19 monitoring points are arranged from the west to the east, which is along Lekai Street to the East Second Ring Road, involving the main stream of Fu River, Qingshui River, Hou River, Yimuquan River, moat and other tributaries (Fig. 1). The monitoring area is surrounded by schools, residential areas and commercial areas.

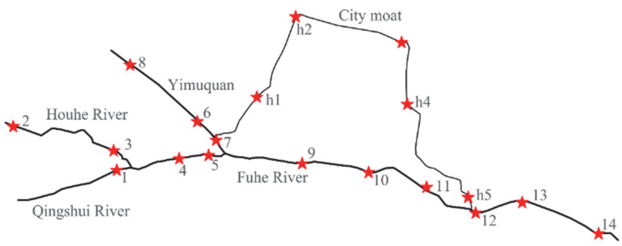

Figure 1 Monitoring points of Baoding downtown section of Fu River

2.2 Sample Collection and Determination Methods

2.2.1 Sample Collection

Samples were collected every 20 days over 8 months in 2018 using a 0.5 m organic glass water sampler, including pH, turbidity, dissolved oxygen, chemical oxygen demand (COD), ammonia nitrogen and total phosphorus. During sampling, the organic glass water sampler is used to take samples at a depth of 0.5 m underwater. 500 ml samples were collected from each monitoring section. The dissolved oxygen and pH value indicators of water samples were detected and recorded in real time on the site. After the on-site collection and recording, the water samples were put into the collection box and transported back to the laboratory for storage in a 4 ℃ incubator, other indicators were determined within 24 h according to the methods in the Methods for Detection and Analysis of Water and Wastewater (Version III) (Supplement).

2.2.2 Water Quality Measurement Method

The pH value is measured using a Hema handheld pH meter (PH-828); Turbidity is measured using a ZD turbidity meter; Dissolved oxygen is measured using a portable dissolved oxygen analyzer (LH-DO2M); The chemical oxygen demand (COD) was measured using a COD rapid digestion instrument (LH-12F); Ammonia nitrogen was determined by Nessler's reagent spectrophotometry (HJ535-2009); Total phosphorus is determined according to the ammonium molybdate spectrophotometric method (GB 11893-89).

2.3 Water Quality Evaluation Method

2.3.1 Canadian Water Quality Index Method

The full name of the Canadian Council of Ministers of the Environment Water Quality Index (CCME-WQI) is the Canadian Council of Ministers of the Environment Water Quality Index. Its evaluation indicators and standards are selected flexibly, and the evaluation results are concise and easy to understand, which is beneficial for improving public understanding of water quality evaluation information. It is one of the widely used water environment evaluation methods worldwide [24]. This index measures the pollution status of water bodies from three perspectives: the range, frequency, and extent of exceeding the standard of evaluation indicators. By constructing a dimensionless index, it succinctly and intuitively reflects the comprehensive water quality status of the study area [25], and can comprehensively evaluate the water quality of a certain period [26]. This index is not only widely used in Canada, but also by the United Nations Environment Programme to assess the quality of drinking water in different countries around the world [27]. However, as a deterministic index, CCME-WQI also has the problem of "jumping" in the evaluation results when the pollutant concentration approaches the evaluation standard value, leading to incomplete evaluation results.

2.3.2 Weighted Euclidean Distance Method

The principle of the weighted Euclidean distance method is that for an assessment unit, the weight is calculated according to the contribution ratio of each pollutant, and then n pollution factors are selected to establish an n-dimensional space with the pollution factor as the coordinate axis. Class I water quality in the water quality standard is taken as the "origin", and then the weighted Euclidean distance between each assessment unit and the "origin" is calculated with the weight, so as to obtain the water quality assessment results.

2.3.3 Fuzzy Comprehensive Evaluation Method

The fuzzy comprehensive evaluation method is a water quality evaluation method based on the membership degree theory of fuzzy mathematics, which transforms qualitative evaluation into quantitative evaluation [28, 29]. The basic idea of this method is to select different pollution factors, establish a membership matrix according to the degree of membership of each level standard, determine the weight of each factor by using the method of exceeding the standard, multiply the weight set of each factor by the membership matrix, and finally obtain a comprehensive evaluation set, indicating the degree of membership of water quality to the standard water quality at all levels, so as to determine the water quality [30]. The fuzzy comprehensive evaluation method can objectively reflect the actual situation of water quality by explaining and distinguishing some objective fuzzy concepts and phenomena in the comprehensive evaluation of water quality, such as pollution level and water quality category. However, the calculation process of this method is relatively complex.

3 RESULTS AND DISCUSSION

3.1 Canadian Water Quality Index Method

In 2016, Hebei Province issued and implemented the Water Pollution Prevention and Control Work Plan of Hebei Province, which requires that the pollution sources of lakes in Hebei Province should be eradicated by 2020, and the main water areas stability should meet the Class III standard for surface water. Therefore, when using the Canadian water quality index method to evaluate the water quality of Baoding downtown section of the Fu River, Class III surface water is used as the evaluation standard.

Table 1 Water quality classification

Grade	Range of index	Note
Very good	(94, 100]	The monitored water quality basically meets the corresponding standards.
Good	(79, 94]	The monitored water quality rarely deviates from the corresponding standard.
Medium	(64, 79]	The monitored water quality occasionally deviates from the corresponding standard.
Pass	(44, 64]	The monitored water quality often deviates from the corresponding standard.
Bad	[0, 44]	The monitored water quality cannot meet the corresponding standard.

The water quality index calculated by the Canadian water quality index method is between 0 and 100. The water quality is divided into five different grades according to the score (Tab. 1).

The assessment results are shown in Fig. 2. The water quality indexes of 19 monitoring points range from 1.57 to 64.44. In spring, the Canadian water quality index of Baoding downtown section of Fu River is 3.27 ~ 16.33, 1.57 ~ 7.45 in summer, 2.91 ~ 32.23 in autumn and 16.93 ~ 64.44 in winter. It can be seen from the assessment results that during the monitoring period, the water quality of Baoding downtown section of the Fu River fails to meet the Class III surface water standard in spring, summer and autumn. The water quality is worse than in winter. The water quality index of 10 monitoring points is above 44, and the water quality is qualified.

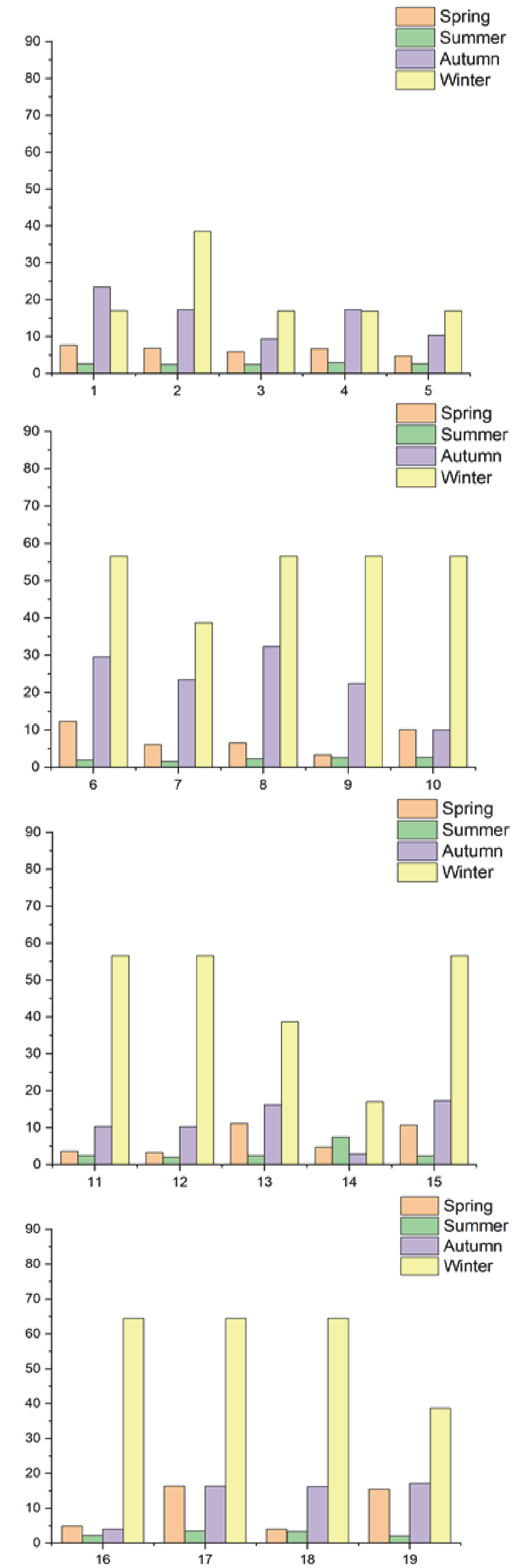

Figure 2 Evaluation results of Canadian water quality index method for spring, summer, autumn, winter

It can be seen from the Canadian water quality index evaluation method that the water quality of Fu River (Baoding Downtown section) throughout the year is poor and does not meet the Class III water standard. The water quality in autumn and winter is higher than that in spring and summer. This indicates that the Canadian Water Quality Act can preliminarily evaluate whether water quality is qualified, but lacks evaluation of various indicators that affect water quality.

3.2 Weighted Euclidean Distance Method

Tab. 2 shows the average weight of each pollution factor in Baoding downtown section of Fu River in the whole year according to the weighted European distance method. It can be seen from Tab. 2 that the factor weights of ammonia nitrogen and total phosphorus are significantly higher than the other two pollution factors, and they are the main pollution factors in Baoding downtown section of the Fu River in 2018. The factor weights of ammonia nitrogen and total phosphorus are significantly higher than the other two pollution factors, indicating the cause of eutrophication in water bodies, which is consistent with Miranda's study [31].

Table 2 Factor weights obtained by weighted Euclidean distance method

Sampling point	DO	COD_{Cr}	Ammonia nitrogen	Total phosphorus
1	0.030	0.054	0.341	0.575
2	0.022	0.034	0.248	0.697
3	0.030	0.036	0.262	0.673
4	0.018	0.048	0.316	0.619
5	0.018	0.036	0.330	0.616
6	0.038	0.082	0.440	0.441
7	0.027	0.043	0.305	0.626
8	0.046	0.075	0.412	0.468
9	0.026	0.034	0.428	0.512
10	0.025	0.066	0.345	0.564
11	0.021	0.040	0.354	0.586
12	0.024	0.045	0.381	0.549
13	0.026	0.038	0.416	0.520
14	0.022	0.035	0.361	0.583
h1	0.041	0.151	0.394	0.414
h2	0.043	0.057	0.414	0.486
h3	0.035	0.055	0.374	0.536
h4	0.031	0.064	0.329	0.577
h5	0.022	0.042	0.324	0.612
Average value	0.029	0.054	0.356	0.561

The evaluation results of weighted Euclidean distance method are shown in Tab. 3. It can be seen that the water quality in Baoding downtown section of the Fu River is dominated by Class V water. The Euclidean distance of the Fu River in spring, summer and autumn is basically greater than 1. The water quality assessment results in spring and summer are both Class V water. The assessment results of Monitoring Point 1 and Monitoring Point 7 in autumn are respectively 4.366 and 4.848, which are Class IV water. The water quality assessment results of 15 monitoring points in winter can reach Class IV water and above, and the water quality of 7 monitoring points can reach Class II water.

Table 3 Evaluation results of weighted Euclidean distance method

Sampling point	Spring		Summer	
	Euclidean distance δ_i	Evaluation result	Euclidean distance δ_i	Evaluation result
1	1.173	V	2.651	V
2	3.212	V	4.600	V
3	8.743	V	3.332	V
4	6.159	V	2.119	V
5	6.021	V	5.088	V
6	3.937	V	2.958	V
7	4.027	V	4.038	V
8	4.028	V	3.680	V
9	6.536	V	3.379	V
10	5.252	V	3.346	V
11	5.838	V	5.155	V
12	4.543	V	4.045	V
13	5.634	V	3.367	V
14	6.463	V	3.631	V
h1	5.865	V	3.496	V
h2	6.480	V	5.037	V
h3	7.139	V	3.375	V
h4	8.102	V	3.823	V
h5	9.300	V	4.082	V
Sampling point	Autumn		Winter	
	Euclidean distance δ_i	Evaluation result	Euclidean distance δ_i	Evaluation result
1	0.576	4.366	0.374	3.426
2	1.403	V	1.153	V
3	4.053	V	0.826	5.319
4	0.751	5.281	1.282	V
5	0.975	5.913	1.135	V
6	0.624	5.103	0.368	3.186
7	0.689	4.848	0.432	3.445
8	0.846	5.482	0.199	2.420
9	0.797	5.401	0.252	2.746
10	0.905	5.707	0.232	2.632
11	1.064	V	0.587	4.196
12	1.274	V	0.298	2.969
13	1.706	V	0.306	3.014
14	1.765	V	0.348	3.284
h1	0.845	5.492	0.587	4.914
h2	0.743	5.262	0.086	1.772
h3	1.413	V	0.147	2.185
h4	1.411	V	0.223	2.524
h5	1.533	V	0.590	4.131

Table 4 Weights of pollution factors obtained by fuzzy comprehensive evaluation method

Sampling point	DO	COD_{Cr}	Ammonia-nitrogen	Total phosphorus
1	0.113	0.192	0.368	0.327
2	0.093	0.134	0.313	0.460
3	0.110	0.130	0.315	0.445
4	0.070	0.182	0.365	0.384
5	0.073	0.146	0.383	0.398
6	0.186	0.180	0.350	0.283
7	0.173	0.136	0.308	0.383
8	0.119	0.175	0.408	0.298
9	0.084	0.154	0.367	0.395
10	0.098	0.210	0.402	0.290
11	0.100	0.144	0.431	0.325
12	0.089	0.166	0.396	0.348
13	0.099	0.144	0.416	0.341
14	0.088	0.138	0.391	0.384
h1	0.095	0.304	0.347	0.254
h2	0.130	0.173	0.389	0.307
h3	0.115	0.175	0.368	0.342
h4	0.103	0.186	0.345	0.366
h5	0.087	0.158	0.344	0.411
Average value	0.107	0.170	0.369	0.355

3.3 Fuzzy Comprehensive Evaluation Method

The annual average weight of each pollution factor calculated by the method of exceeding the standard is shown in Tab. 4. It can be seen that the annual average weight of total phosphorus calculated by the over-standard method is 0.355, and the annual average weight of ammonia nitrogen is 0.367. The same conclusion is obtained using the weighted Euclidean distance method, and ammonia nitrogen and total phosphorus are the main pollution factors in the monitoring period.

Fig. 3 shows the evaluation results of the fuzzy comprehensive evaluation method. It can be seen that in the three seasons of spring, summer and autumn, the membership of 19 monitoring points to Class V water is much higher than that of other types of water, and the membership of most monitoring points to Class V water is 0.9 ~ 0.98. Among them, Class V water at Monitoring Point 3 in spring has the highest degree of subordination, which is 0.954, and Class V water at Monitoring Point 12 in summer has the highest degree of subordination, which is 0.958. Class V water at monitoring point 3 in autumn has the highest degree of membership, that is 0.836. The water quality has improved significantly in winter. Most of the monitoring points have the highest degree of subordination to Class IV water, and the monitoring points 1, 8, 9, 12, 13, 14, 16, 17 and 18 have the highest degree of subordination to Class III water. The main reason is that Baoding government carried out dredging work for the Fu River in 2018, and there is less rainfall in winter, thus reducing non-point source pollution. Ye et al. [32] also used the fuzzy comprehensive evaluation method to evaluate the water quality of the Taihu Lake Lake, and the trends were roughly the same as those in this paper, indicating the pollution degree of water quality.

In general, the degree of subordination of Baoding urban section of Fu River to Class V water quality standards in different seasons throughout the year is in the order of spring (0.9216) > summer (0.9110) > autumn (0.5539) > winter (0.1639).

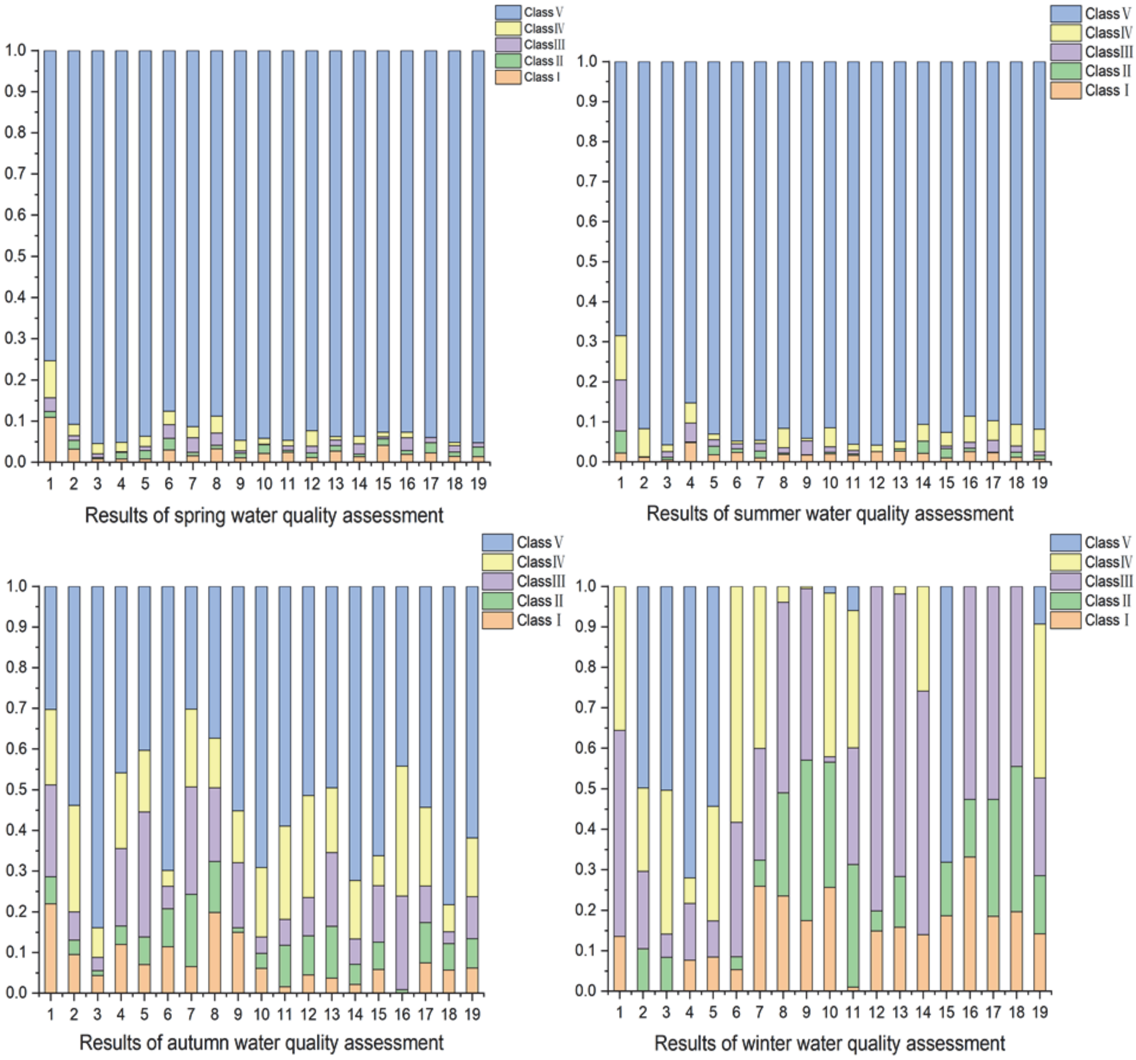

Figure 3 Evaluation results of fuzzy comprehensive evaluation method

3.4 Comparison and Analysis of Water Quality Assessment Results

Among the three water quality assessment methods, the Canadian water quality index method is relatively simple. The final calculation results are determined from such three aspects as scope, frequency and amplitude, which can suppress the impact of extreme indicators. However, for short-term monitoring tasks, the Canadian Water Quality Index (CWI) method has strong concealment, so the evaluation results may not be comprehensive enough. The evaluation results of the weighted European distance method not only indicate the water quality categories of the monitored sections, but also indicate the closeness of different water quality standards. Compared with the Canadian water quality index method, the evaluation results are more diversified and can better reflect the water quality. The fuzzy comprehensive evaluation method uses the membership function to determine the water quality of the monitoring points, which can better reflect the pollution status of the monitoring points, and the evaluation results are more objective and hierarchical. In addition, the weighted Euclidean distance method and the fuzzy comprehensive evaluation method both give weight to the four pollution factors, but the calculated weight of each pollution factor is different. This is because when the fuzzy comprehensive evaluation method is used to calculate the weight, only the standard values of evaluation factors I ~ V are simply averaged, highlighting the impact of indicators with large measured concentrations on the results.

4 CONCLUSIONS

This study evaluated the water quality of the Fu River in Baoding City, China using three methods: Canadian Water Quality Index, Weighted Euclidean Distance, and Fuzzy Comprehensive Evaluation. The following key conclusions emerged: All three assessment techniques indicated consistently poor water quality in the Fu River, with the primary pollution sources being ammonia nitrogen and total phosphorus. The Canadian Index provided relatively simple water quality rankings. In contrast, the Weighted Euclidean and Fuzzy Comprehensive methods offered more nuanced, multi-dimensional evaluations by incorporating principles of fuzzy mathematics. Of the three methods, Fuzzy Comprehensive Evaluation provided the most hierarchical and objective assessment results for the specific conditions of the Fu River site. Employing multiple water quality evaluation methods, rather than relying on just one, can produce more robust insights into the overall water quality profile. The findings provide guidance for selecting appropriate site-specific water quality assessment methods that offer holistic insights to inform management and remediation efforts. Further studies could build on these results by expanding the suite of evaluation techniques, sampling parameters, or study duration and locations along the Fu River. In summary, this comparative water quality assessment highlights the utility of leveraging different evaluation techniques to develop a comprehensive understanding of river water quality. The findings provide both practical guidance for water quality monitoring, as well as a methodological framework for combining complementary water quality indices.

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