Water Pollution Characteristics and Assessment of Lower Reaches in Haihe River Basin

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Abstract

21 water samples were collected from the lower reaches in Haihe River Basin and the pollutant content was detected in May, 2009. The water quality of 11 rivers in this area was assessed with the methods of Single Factor Assessment Method, Comprehensive Pollution Index Method, Fuzzy Comprehensive Evaluation Method and Water Quality Identification Index Method. The results showed that Water Quality Identification Index Method is suitable for water quality assessment of the lower reaches in Haihe River Basin; Single-factor Water Quality Identification Index Method showed that the main pollutants were total nitrogen, ammonia nitrogen, COD, BOD5, permanganate index, fluoride; the pollution belonged to organic and abundant nutrition pollution. Water pollution of all assessed rivers was serious, and inferior class IV rivers accounted for 81.8%. The water quality of Qingjinghuang Drain (8.972), Yongding New River (9.654), Ziya New River (10.877), North Drainage River (11.094), Beitang Drainage River (11.376), and the Dagu Drainage River (14.388) was inferior class IV and malodorous black, and the pollution level increased orderly. The pollution of rivers in the south of Haihe River was more serious than that in the north.

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Keywords: Haihe River Basin, pollution characteristics, water quality assessment, Water Quality Identification Index Method;

1. Introduction

The shortage of water resource and the water pollution are very serious in Haihe River Basin, which has been one of the most serious pollution regions in China. The lower reaches in Haihe River Basin, including Ziya New River, Duliujian River, Haihe River, Yongding New River, Chaobai New River and Jiyun River etc, receive the domestic, industrial, agricultural wastewater discharged upstream, so the pollution is particularly serious. Environment monitoring and a reasonable assessment should be made to help government make the right judgments and finally achieve the goal of river ecological remediation.

The monitoring and assessment work on water quality in Haihe River Basin has been widely carried out. The changes of river water quality were analyzed by Zhang [1] based on the data of six large-scale monitoring in china from 1980 to 2000. The situation was serious and became worse and worse [2]. Water quality of Haihe River Basin in 2006 was analyzed with the Single Factor Assessment Method and the results showed that 63.8% of the water function zones did not meet the standard [3]. For the lower reaches in Haihe River basin especially in Tianjin area, however, monitoring and assessment of water quality were rarely reported.

Up to now, there is no water quality assessment model which is widely acceptable and comparable [4-6]. And the applicability and rationality of water quality assessment method have become the focus to environmental workers.

To understand the pollution situation and characteristics accurately, 21 water samples were collected from the lower reaches in Haihe River Basin and the pollutants were measured in May, 2009. The water quality was analyzed with the methods of Single Factor Assessment Method, Comprehensive Pollution Index Method, Fuzzy Comprehensive Assessment Method and Water Quality Identification Index Method.
Quality Identification Index Method, and their advantages and disadvantages of were compared and analyzed. And pollution characteristics were also obtained in this study.

2. Assessment Methods

2.1. Single Factor Assessment Method

Single Factor Assessment Method means that water pollution grade is determined by the worst pollution index [7-9].

2.2. Comprehensive Pollution Index Method (C)

Based on the assessment of Single Factor Index and considering the combined effect of all factors evaluated, comprehensive pollution index was calculated through different mathematical models [10-12] and determine the pollution degrees by the appropriate method [13]. The $C$ can be expressed by the following formula:

$$\begin{align*}
C &= \frac{1}{n} \sum_{i=1}^{n} C_i
\end{align*}$$

(1)

where $n$ is the pollutants number; $C_i$ is the single factor pollution index; The $C$ of $\leq 1$ shows that water quality is up to the standard used, and the $C$ of $<1$ indicate water quality accords with the standard.

Table 1. Comprehensive water quality classification based on Comprehensive Pollution Index $C$

<table>
<thead>
<tr>
<th>$C$</th>
<th>Class</th>
<th>Water Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>$C &lt; 0.8$</td>
<td>Qualified</td>
<td>Some pollutants are detected but their concentrations accord with the standard</td>
</tr>
<tr>
<td>$0.8 &lt; C \leq 1.0$</td>
<td>Basically Qualified</td>
<td>Concentrations of some pollutants exceed the standard</td>
</tr>
<tr>
<td>$1.0 &lt; C \leq 2.0$</td>
<td>Polluted</td>
<td>Concentrations of quite a part of pollutants exceed the standard</td>
</tr>
<tr>
<td>$C &gt; 2.0$</td>
<td>Serious Polluted</td>
<td>Concentrations of quite a part of pollutants exceed the standard many times</td>
</tr>
</tbody>
</table>

2.3. Fuzzy Comprehensive Evaluation Method

Through function relationships (membership function), Fuzzy comprehensive evaluation method transferred the measured values which reflected the water pollution to the quality values which reflected the quality degree of water. A membership matrix can be established by the relations of the monitoring data and each grade in national water quality standards. Then in order to get the comprehensive assessment set which shows the membership grade of the water quality, one can multiply the weight factor by membership matrix. The water quality grade can be determined by the largest value and its corresponding grade [14-17].

2.4. Water Quality Identification Index Method

2.4.1. Single-factor Water Quality Identification Index ($P_i$)

The $P_i$ [18] consists of integer and decimal fraction. Pollution grade can be judged by integer and the difference of pollution degree in same grade can be judged by decimal fraction. The $P_i$ can be expressed by the following formula:

$$P_i = X_i \cdot X_{i+1}$$

(2)
where \( X_1 \) is the integer, and shows the grade of water quality; \( X_2 \) is the decimal fraction, and shows the degree of monitoring data in interval of \( X_1 \) class water quality changing; \( X_i \) is the comparison result of water quality grade and function goal grade.

(1) \( X_1.X_2 \) calculation

When the water quality grade is between I and V:

a. For the general indicators (except dissolved oxygen, pH, temperature and so on),

\[
X_1.X_2 = a + \frac{C_i - C_{us}}{C_{us} - C_{ls}} \tag{3}
\]

b. For dissolved oxygen:

\[
X_1.X_2 = a + 1 - \frac{C_i - C_{us}}{C_{us} - C_{ls}} \tag{4}
\]

where \( C_i \) is the monitoring value of \( i \) target; \( C_{us} \) is the upper limit of \( i \) target in water quality standard interval of class \( a \); \( C_{ls} \) is the lower limit of \( i \) target in water quality standard interval of class \( a \); \( a = 1,2,3,4,5 \), based on monitoring data and national standards.

When the water quality is worse than or equal to V:

a. For general indicators (except dissolved oxygen, pH, temperature and so on),

\[
X_i.X_2 = 0 + \frac{C_i - C_{us}}{C_{us} - C_{ls}} \tag{5}
\]

b. For dissolved oxygen:

\[
X_i.X_2 = 0 + \frac{C_i - C_{us}}{C_{us} - C_{ls}} \cdot m \tag{6}
\]

where \( C_{ls} \) is the lower limit of \( i \) target in water quality standard interval of class \( V \); \( m \) is the correction coefficient, \( m = 4 \) in this study.

(2) \( X_3 \) calculation

\[
X_3 = X_i - f_i \tag{7}
\]

where \( f_i \) is the goal grade of water environment functional area, Note: When \( X_3 > 9 \), \( f_i = 9 \).

2.4.2. Comprehensive Water Quality Identification Index (Iwq)

The \( I_wq \) [19], a river water quality assessment index based on Single Factor Water Quality Identification Index, can be calculated by the following formula:

\[
I_wq = C_1.C_2.X_3.X_4 \left( \frac{1}{m+1} \left( \sum_{j=1}^{m} P_j + \frac{1}{n} \sum_{j=1}^{n} P_j \right) \right) \tag{8}
\]

where \( C_1.C_2 \) shows comprehensive water quality index; \( P_i \) is single factor water quality index of the main pollution indicator (that is \( X_1.X_2 \) in single factor water quality identification index), and each indicator takes up one weight; \( m \) is the number of the main pollution indicators; \( P_j \) is single factor water quality index of other indicators, and all the non-main pollution indicators take up one weight; \( n \) is the number of non-major pollution indicators; \( X_3 \) is the number of indicators which are worse than water quality standards grade among all index; \( X_4 \) represents the comparison results of water quality categories and function zoning category. According to 2008 Bulletin for Chinese Environment Quality, ammonia nitrogen, BOD5 and permanganate index were selected as main pollution indicators in this study.
2.4.3. Determination of water quality grade

River water quality grade can be determined based on $C_1, C_2$ of $I_{wq}$ (Tab.2).

<table>
<thead>
<tr>
<th>Judging basis</th>
<th>Comprehensive water quality grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1.0 \leq C_1, C_2 \leq 2.0$</td>
<td>I</td>
</tr>
<tr>
<td>$2.0 &lt; C_1, C_2 \leq 3.0$</td>
<td>II</td>
</tr>
<tr>
<td>$3.0 &lt; C_1, C_2 \leq 4.0$</td>
<td>III</td>
</tr>
<tr>
<td>$4.0 &lt; C_1, C_2 \leq 5.0$</td>
<td>IV</td>
</tr>
<tr>
<td>$5.0 &lt; C_1, C_2 \leq 6.0$</td>
<td>V</td>
</tr>
<tr>
<td>$6.0 &lt; C_1, C_2 \leq 7.0$</td>
<td>Inferior V, not malodorous black</td>
</tr>
<tr>
<td>$C_1, C_2 &gt; 7.0$</td>
<td>Inferior V, and malodorous black</td>
</tr>
</tbody>
</table>

Table 2. Comprehensive water quality grade based on Comprehensive Water Quality Identification Index

3. Collection and Analysis of Samples

Waters samples were collected from 21 monitoring sections (Figure 1) of Lower Reaches in Haihe River Basin in May, 2009 including Jiyun River, Chaobai New River, Yongding New River, Jinzhong River, Beitang Drainage River, Haihe River, Dagu Drainage River, Duliujian River, Qingjinghuang Drain, Ziya New River and North Drainage River. Water samples were collected in dry season (in May), 2009, and the pollutions were measured. Water samplings complied with methods from Monitoring Technical Specifications for Surface Water and Wastewater (HJ/T91-2002). Pollutants measure complied with methods from the National Environmental Quality Standards for Surface Water [20]. The data used in this paper were the average values of monitoring data from corresponding sections.

4. Water Quality Assessment of Lower Reaches in Haihe River Basin

4.1. Assessment indicators and standards

In research, the adopted water quality assessment standard is the National Surface Water Environmental Quality Standard (GB3838-2002) [20], which is a primary criterion of assessing river water environment quality. In the standard, water environment quality was divided into five grades according to surface water environment function and protection objective. Fifteen factors were selected as the assessment indexes, including DO (dissolved oxygen), permanganate index, COD (chemical
4.2. Results and Discussion

4.2.1. Assessment results

Utilizing the mentioned methods, the assessment results could be calculated (Table 3). From the assessment results, it could be seen that:

(1) Water quality of 11 rivers was inferior $V$ according to single factor assessment method. It is can be seen that the results of single factor assessment method are excessive protection because the river water pollution grade is determined by the worst pollution index. Single factor assessment method only considered the most prominent factor to show its maximum influence on the overall assessment results. And the roles of other factors were weakened.

(2) Comprehensive Pollution Index Method showed that only Chaobai new River’s water quality was qualified, the other rivers’ water quality was contaminated or serious polluted. Although Comprehensive Pollution Index Method could determine whether water quality accorded with functional areas’ goals, it couldn’t determine the class of comprehensive water quality.

(3) Fuzzy Comprehensive Evaluation Method showed that water quality was $V$ for each river. However, from the degree of membership of $V$, the membership reached more than 0.72 and even some were more than 0.95, which showed that the water pollution was very serious and it may be worse than $V$. Due to the basis of assessment method, it couldn’t reflect water pollution degree of these rivers which were worse than $V$. Fuzzy comprehensive evaluation method was suitable for assessing water quality between $I$ ~ $V$. But when water quality was inferior $V$, its results are still $V$ and the conclusions are conservative.

(4) Water quality identification index method showed that chaobai new River’s and Duliujian River’s water quality were $V$; water quality of Jiyun River, jinzhou River and Haihe River were inferior class $V$ and not malodorous black; water quality of Dagu Drainage River, Beiantang Drainage River, North Drainage River, Ziya New River, Yongding New River and Qingjinghuang Drain were inferior class $V$ and malodorous black. Through the comparison of $I_{aq}$, Ziya New River (10.877), North Drainage River (11.094), Beiantang Drainage River (11.376) and Dagu Drainage River (14.388) were seriously polluted. Assessment results were in accorded with the actual situation, so assessment results had high accuracy and reliability. It showed that water quality identification index method can make reasonable assessments, especially for inferior $V$ rivers. It solved the problem of continuous description of inferior class $V$. In this method, pollution degrees are divided into seven grades, such as class $I$, class $II$, class$III$, class$IV$, class $V$, inferior class $V$ not malodorous black and inferior class $V$ and malodorous black. If $C_1 \cdot C_2 > 6.0$, the river water quality was inferior $V$. The larger the value was, the worse the water quality was, which showed that this method achieved both qualitative and quantitative assessment.

4.2.2. Distribution characteristic of water quality identification index

(1) Analysis of Main Pollutants

Average values of all indicators’ single factor water quality identification index were calculated, and the changing trend figure of average values could also be obtained (Figure 2). From Fig.2, it could be seen that total nitrogen and ammonia nitrogen were the main pollutants, followed by COD, BOD$_5$, Permanganate Index and Fluoride. The situation belonged to organic and abundant nutrition pollution; Single factor water quality identification index ($P_i$) for ammonia nitrogen was from 4.50 to 29.79 and the average value was 13.91, worse than class $V$ 8 grades. The concentrations of NH$_3$-N in 21 monitoring sections were from 0.435 to 58.77mg/L. The concentrations of NH$_3$-N in Dagu Drainage River, Beiantang Drainage River and Ziya New River were the first three, which were 24.7, 19.5, 17.4 times more than $V$ standard (2.0mg/L), respectively. The $P_i$ for COD was from 5.80 to 23.49, and 10 rivers’ water quality were inferior class $V$ and the worse one exceeded 18.5 times. The $P_i$ for BOD$_5$ was from 4.90 to 16.19 and the average value was 8.97, which exceeded class $V$ 3 grades, and the most serious one exceeded the standard more than 11 times. The $P_i$ of permanganate index was from 4.40 to 11.96 and the average value was 6.62. The $P_i$ of Fluoride was from 6.31 to 6.91 and all the 12 rivers exceeded the standard $V$.

(2) Distribution Characteristic of Comprehensive Water Quality Identification Index

Based on $I_{aq}$ and grading basis (Table 2), water quality grade of monitoring rivers could be determined (Table 3). The average value of $I_{aq}$ for 11 rivers was 8.816 and overall water quality was serious. The percentage of the inferior class $V$ rivers was up to 81.8% in May, 2009. Water quality of Dagu Drainage River, Beiantang Drainage River, North Drainage River, Ziya New River, Yongding New River and Qingjinghuang Drain was worse; chaobai new River and Duliujian River’s water quality was relatively good which was in accorded with class $V$. oxygen demand, BOD$_5$ (biological oxygen demand), TP (total phosphorus), NH$_3$-N (ammonia nitrogen), TN (total nitrogen), Cu (copper), Pb (Lead), Zn (zinc), Cd (cadmium), Cr (hexavalent chromium), Hg (mercury), As (arsenic), fluoride.
Table 3. Assessment Results with various water quality methods

<table>
<thead>
<tr>
<th>Item</th>
<th>Single Factor Index Method</th>
<th>C and quality assessment</th>
<th>Fuzzy Comprehensive Evaluation</th>
<th>$I_{wq}$ and water quality grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jiyun River</td>
<td>IC - V</td>
<td>(1.27) Polluted</td>
<td>V (0.82)</td>
<td>IC - V, not malodorous black (6.541)</td>
</tr>
<tr>
<td>Chaobai new River</td>
<td>IC - V</td>
<td>(0.98) Qualified</td>
<td>V (0.73)</td>
<td>V (5.140)</td>
</tr>
<tr>
<td>Yongding New River</td>
<td>IC - V</td>
<td>(3.08) S-P</td>
<td>V (0.93)</td>
<td>IC - V, not malodorous black (9.854)</td>
</tr>
<tr>
<td>Jinzhong River</td>
<td>IC - V</td>
<td>(1.34) S-P</td>
<td>V (0.87)</td>
<td>IC - V, not malodorous black (6.951)</td>
</tr>
<tr>
<td>Beitang Drainage River</td>
<td>IC - V</td>
<td>(4.20) S-P</td>
<td>V (0.97)</td>
<td>IC - V, not malodorous black (11.676)</td>
</tr>
<tr>
<td>Haihe River</td>
<td>IC - V</td>
<td>(1.82) Polluted</td>
<td>V (0.84)</td>
<td>IC - V, not malodorous black (6.551)</td>
</tr>
<tr>
<td>Dagu Drainage River</td>
<td>IC - V</td>
<td>(5.56) S-P</td>
<td>V (0.98)</td>
<td>IC - V and malodorous black (13.888)</td>
</tr>
<tr>
<td>Duliujian River</td>
<td>IC - V</td>
<td>(1.44) Polluted</td>
<td>V (0.81)</td>
<td>V (5.040)</td>
</tr>
<tr>
<td>Qingjinghuang Drain</td>
<td>IC - V</td>
<td>(2.96) S-P</td>
<td>V (0.96)</td>
<td>IC - V and malodorous black (7.472)</td>
</tr>
<tr>
<td>Ziya New River</td>
<td>IC - V</td>
<td>(4.76) S-P</td>
<td>V (0.97)</td>
<td>IC - V and malodorous black (12.277)</td>
</tr>
<tr>
<td>North Drainage River</td>
<td>IC - V</td>
<td>(4.39) S-P</td>
<td>V (0.98)</td>
<td>IC - V and malodorous black (9.094)</td>
</tr>
</tbody>
</table>

IC - V: Inferior Class V; S-P: Serious Polluted

From $I_{wq}$ of May, $I_{wq}$ of rivers except chaobai new River and Duliujian River was greater than 6.0. Even $I_{wq}$ of Dagu Drainage River, Beitang Drainage River, North Drainage River, Ziya New River, Yongding New River and Qingjinghuang Drain was greater than 7.0 and their water quality was inferior class V and malodorous black, which was in accorded with actual situations.

From $I_{wq}$ the average value of Haihe River, Dagu Drainage River, Duliujian River, ZiyaNew River and North Drainage River is $I_{wq}$ was 9.637, the average $I_{wq}$ value of rivers in the north of Haihe River was 7.830. So those rivers in the south of Haihe River were polluted more seriously.

5. Conclusions

The results of Single Factor Assessment Method are too harsh; Comprehensive Pollution Index Method can not directly determine comprehensive water quality grade; when the comprehensive water quality is inferior class V, the results of Fuzzy Comprehensive Evaluation Method are conservative; water quality identification index method can express the comprehensive water quality information, which is both qualitative and quantitative, especially for the inferior V. Therefore it is a kind of water quality assessment method that can be promoted.

According to the assessment results of water quality identification index method, water pollution of Lower Reaches in Haihe River Basin was serious in May, 2009 and the main pollutants were TN, NH$_3$-N, COD, BOD$_5$, permanganate index, fluoride; the kind of pollution is organic and abundant nutrition pollution; water pollution of all rivers assessed was serious, and inferior class V rivers accounted for 81.8%. The water quality of Qingjinghuang Drain (8.972), Yongding New River (9.654), Ziya New River (10.877), North Drainage River (11.094 ), Beitang Drainage River (11.376), and the Dagu Drainage River (14.888) was inferior class V and malodorous black, and the pollution degree increased orderly; the pollution of rivers in the south of Haihe River was more serious than that in the north.

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