Water quality assessment in China Ningxia Section of the Yellow River using water quality identification index method

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Abstract. The water quality of the Yellow River is related to the healthy development of industry and agriculture in Ningxia. According to the Ningxia Water Resources Bulletin 2012-2017, we selected three representative water quality indicators of ammonia nitrogen (NH₃-N), total phosphorus (TP) and permanganate index (COD₅Mn), and applied the single-factor and comprehensive water quality identification index method to evaluate the water quality of six national control sections in the Ningxia section of the Yellow River. The results showed that each section was most affected by NH₃-N, followed by TP, and least affected by COD₅Mn; The single-factor identification indexes of six sections were mostly falls into the category II, and the comprehensive identification indexes showed that the water quality mainly fell into the category II; Affected by the rapid development of the industry in this region, the water quality of the Mahuanggou section was seriously polluted.

1. Introduction
Ningxia is one of the six areas with severe water shortage, and water is the lifeline of its agricultural, industrial and social economic development. Water environmental protection is the primary task of environmental protection in Ningxia. Hence, the quality of the Yellow River directly affects the industrial and agricultural production, the safety of human and animal drinking water and the healthy development of the ecological environment. Since the 1990s, especially the development of the western development strategy, the social and economic development of Ningxia has entered a period of rapid development, but the pressures of water pollution and ecological environmental protection have also increased. The problem of water shortage caused by pollution and water environment safety is becoming more and more serious [1-2]. Meanwhile, the number of industrial parks in Ningxia has been increasing, such as Ningdong Coal Chemical Industry Base, Ningdong Energy Chemical Industry Base and Dawukou Economic Development Zone, which made industrial water increase, bringing more serious challenges to the water environment in this region. Therefore, it is particularly important and urgent to assess the water quality of the Ningxia section of the Yellow River.

In response to the above problems, many scholars conducted a series of investigations and studies. Liu [3], Zhang et al [4] and Lin et al [5] analyzed the water quality status and trend changes in the Ningxia section of the Yellow River and analyzed their possible sources of pollution. Xiang et al [6] used principal component analysis to evaluate the water quality of the national control section of the Yellow River Basin, and found that the pollution in the section of Shanxi Yuncheng, Shaanxi Weinan
and Inner Mongolia Wuhai was more serious. Hou et al [7] used WASP water quality model, fuzzy clustering and matter-element analysis to analyze the water quality of Ningxia section of the Yellow River and put forward scientific section optimization suggestions. This paper selected NH$_3$-N, TP and COD$_{Mn}$ of main pollutants of the Yellow River in Ningxia section as the assessment index, the single-factor water quality identification index method and comprehensive water quality identification index method were used to assess the water quality of the mainstream, which provides a scientific basis for the targeted improvement of the water quality of the Ningxia section of the Yellow River.

2. Materials and method

2.1. Study area and samples

The Yellow River in Ningxia section entered Nanchangtan, passing through the Weining Plain and the Yinchuan Plain, and finally exited at the Mahuanggou, with a total length of 397 km, accounting for 7.2% of the total length of the Yellow River. The average annual inflow water volume is 31.7 billion m$^3$, the outbound water volume is 29.4 billion m$^3$, and the average maximum peak flow rate is 3570 m$^3$/s [7]. The annual average temperature in this region is 8.89 °C, the average annual rainfall is 182.61 mm, and the average annual evaporation is 2075.11 mm. There are six national control sections in mainstream, namely Xiaheyan (105°03′19″E, 37°27′16″N), Jinshawan (105°56′34″E, 37°50′13″N), Yesheng Highway Bridge (106°12′9.8″E, 38°04′47.7″N), Yingu Highway Bridge (106°24′40.2″E, 38°21′31.8″N), Pingluo River Bridge (106°39′59″E, 38°48′44.7″N) and Mahuanggou (106°47′23.2″E, 39°20′59.9″N) (Figure 1). The data of this study was from the Environmental Monitoring Center of Ningxia, and the water quality monitoring frequency is 1 time per day.

![Figure 1. The position diagram of national control section.](image-url)
2.2. Water quality index method

2.2.1. Single-factor water quality identification index. The single-factor water quality identification index \( P_i \) can completely identify important information such as water quality assessment index, water quality data and functional area target value \[8\]. \( P_i \) consists of integer and decimal fraction. Pollution grade can be judged by integer and difference degree can be judged by decimal fraction \[9\], and its form is:

\[
P_i = X_1X_2X_3
\]

where, \( X_1 \) is the water quality category of the \( i \)-th water quality index; \( X_2 \) is the position of the monitoring data of the water quality index in the \( X_1 \) water quality change interval; \( X_3 \) is the comparison result of the water quality grade and the functional goal grade, reflecting the level of pollution of assessment indicators. Water quality monitoring results showed that the water quality category was between I and V, so \( X_2 \) is generally calculated by the following formula:

\[
X_2 = \frac{\rho_i - \rho_{kmin}}{\rho_{kmax} - \rho_{kmin}}
\]

where, \( \rho_i \) is the measured concentration of the \( i \)-th water quality index, \( \rho_{kmax} \) is the upper limit of the \( k \)-th water zone concentration, and \( \rho_{kmin} \) is the lower limit of the \( k \)-th water zone concentration.

2.2.2. Comprehensive water quality identification index. Comprehensive water quality identification index \( I_{eq} \) \[8\] is a \( P_i \)-based comprehensive analysis index in the form of :

\[
I_{eq} = C_1C_2X_3X_4
\]

\[
C_1C_2 = \frac{1}{n} \sum_{i=1}^{n} P_i
\]

where, \( C_1 \) is the category of comprehensive water quality; \( C_2 \) is the location within the \( C_1 \) water quality change interval; \( X_3 \) is the number of individual index in the water quality indicators participating in the comprehensive water quality assessment, which is inferior to the water environment functional zone target; \( X_4 \) is the comparison result of the comprehensive water quality category and the functional area setting category. The criteria for determining the comprehensive water quality level of the comprehensive water quality index method was shown in Table 1 \[8\].

| Range | Comprehensive water quality level |
|-------|----------------------------------|
| 1.0 \( \leq C_1 \) \( \leq 2.0 \) | I |
| 2.0 \( \leq C_1 \) \( \leq 3.0 \) | II |
| 3.0 \( \leq C_1 \) \( \leq 4.0 \) | III |
| 4.0 \( \leq C_1 \) \( \leq 5.0 \) | IV |
| 5.0 \( \leq C_1 \) \( \leq 6.0 \) | V |
| 6.0 \( \leq C_1 \) \( \leq 7.0 \) | Inferior V but not black&stinky |
| \( C_1 \) \( \geq 7.0 \) | Inferior V and black&stinky |

3. Results and discussion

3.1. Discussion on the results of single-factor water quality identification index

According to the single-factor water quality identification index method, the \( P_i \) of NH\(_3\)-N, TP and COD\(_M \) of six national control sections were calculated, the results were shown in Table 2. It can be seen from Table 2 that the single-factor identification index of the six sections from 2012 to 2017 was
mostly the category II water standard. CODMn was category II water standard in all sections, and the water quality entering this province of the Yellow River reached category I water standard in some years. NH3-N and TP were category II water standard in front of the monitoring section of Yingu Highway Bridge, and they were classified as category III water standard in Pingluo River Bridge and Mahuanggou. In general, each section was most affected by NH3-N, followed by TP, and least affected by CODMn.

Table 2. Calculation results of single-factor water quality identification index Pi of each monitoring section.

| Section | NH3-N 2012 | TP 2012 | CODMn 2012 | NH3-N 2013 | TP 2013 | CODMn 2013 | NH3-N 2014 | TP 2014 | CODMn 2014 |
|---------|-------------|--------|-------------|-------------|--------|-------------|-------------|--------|-------------|
| 1#      | 2.40        | 2.80   | 2.20        | 2.30        | 2.70   | 2.20        | 2.40        | 2.10   |
| 2#      | 2.40        | 2.60   | 2.40        | 2.10        | 2.50   | 2.10        | 1.80        | 2.50   | 2.00        |
| 3#      | 2.90        | 2.70   | 2.70        | 2.60        | 3.11   | 2.50        | 2.70        | 2.50   | 2.50        |
| 4#      | 3.01        | 2.90   | 2.50        | 2.60        | 2.90   | 2.40        | 2.50        | 2.50   | 2.40        |
| 5#      | 3.10        | 2.90   | 2.40        | 3.20        | 2.90   | 2.20        | 3.10        | 3.10   | 2.50        |
| 6#      | 3.10        | 2.80   | 2.40        | 3.10        | 3.20   | 2.20        | 3.20        | 3.30   | 2.50        |

3.2. Discussion on the results of comprehensive water quality identification index

According to the \( C_1 \cdot C_2 \) of comprehensive water quality identification index \( I_{wq} \), the comprehensive water quality of the Yellow River mainstream was quantitatively determined, and the results were shown in Table 3. It can be seen that the section of Mahuanggou in 2014 and 2016 was category III water standard, and the other years and sections were category II water standard. By comparing the pollution levels of six sections in six years, we can know that Xiaheyuan and Jinshawan sections were the least polluted, followed by the Yesheng Highway Bridge and the Yingu Highway Bridge section. Pingluo River Bridge section was slightly poor, and the water quality of Mahuanggou section was the worst. From 2012 to 2017, the comprehensive water quality of the Yellow River mainstream in Ningxia was all category II, meeting the target water quality requirements. The comprehensive water quality showed a trend of getting better, from 2.702 to 2.333.

Table 3. Comprehensive water quality identification index and water quality judgment of the Yellow River in Ningxia section from 2012 to 2017.

| Year | 1# | 2# | 3# | 4# | 5# | 6# | Mean | Water quality category |
|------|----|----|----|----|----|----|------|------------------------|
| 2012 | 2.500 | 2.500 | 2.800 | 2.810 | 2.800 | 2.800 | 2.702 | II |
| 2013 | 2.400 | 2.200 | 2.710 | 2.600 | 2.800 | 2.800 | 2.585 | II |
| 2014 | 2.300 | 2.100 | 2.600 | 2.500 | 2.900 | 3.000 | 2.567 | II |
| 2015 | 2.200 | 2.310 | 2.500 | 2.500 | 2.800 | 2.700 | 2.502 | II |
| 2016 | 2.100 | 2.300 | 2.400 | 2.400 | 2.900 | 3.000 | 2.517 | II |
| 2017 | 2.200 | 2.100 | 2.400 | 2.300 | 2.500 | 2.500 | 2.333 | II |
3.3. Water pollution analysis

The pollution of the Yellow River mainstream in Ningxia section mainly comes from extensive industrialized wastewater, urbanized domestic sewage and intensive agricultural wastewater. There are 24 backbone drainage ditch in Ningxia, with a total length of 660.1 km and a drainage capacity of 558.6 m³/s, which is responsible for agricultural water withdrawal, groundwater discharge and partial sewage discharge. The residents along the ditch arbitrarily dumped domestic garbage and discharged sewage, and there were many processing factories and workshops along the line, who discharged industrial wastewater directly into the drainage ditch, which seriously polluted the water body. The drainage ditch in Ningxia has been discharged into the Yellow River, causing the water quality of the Yellow River to be polluted.

From the perspective of spatial changes, the water quality was more seriously polluted by the section of the Yesheng Highway Bridge and later, especially at the section of the Mahuanggou, the water quality was the worst. The above changes were related to the economic development of the cities in Ningxia along the Yellow River. The rapid development of Yinchuan City has caused the water in the middle part of the Yellow River to begin to be polluted. The rapid construction and development of various industrial parks in Shizuishan City also caused a large amount of industrial wastewater to be discharged at a random rate without meeting the national emission standards [10], resulting in the Yellow River being the most polluted in this section.

Therefore, in order to ensure the safe use of water in the Yellow River in the downstream area, it is necessary to increase the supervision and treatment of industrial sewage discharge in the Shizuishan section, improve the legal system and increase penalties, and eliminate pollution from the source.

4. Conclusions

In this paper, the single-factor water quality identification index and comprehensive water quality identification index method were used to assess water quality of the national control section of the Yellow River in Ningxia in the current period from 2012 to 2017. The results show that: The single-factor identification index of six sections was mostly falls into the category II. Each section was most affected by NH₃-N, followed by TP, and least affected by CODₘₒ. The results of the comprehensive water quality identification index method showed that the water quality falls into the category II, meeting the target water quality requirements, and the water quality was good. Although the overall condition of water quality was good, the water pollution situation at the section of Mahuanggou cannot be ignored, and sufficient attention must be paid and corresponding treatment measures must be taken.

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