Water quality assessment using comprehensive water quality index and modified Nemerow index method: A case study of Jinghui Canal, North China

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Abstract. Groundwater is an essential part of water resources for human survival in irrigation regions. In this study, water quality of jinghui canal irrigation area were assessed using the comprehensive water quality index method (CWQI), normal Nemerow index assessment method (NNI) and modified Nemerow index assessment method (MNI). 47 groundwater samples were collected from unconfined aquifers through shallow well during November 2009. The results showed that groundwater quality in the area was poor due to the industrial and agricultural activities. Most of the groundwater samples were identified as Grade IV and Grade V by the comprehensive water quality index method. While majority of groundwater samples were assessed as Grade IV by both NNI and MNI. Besides, the water quality assessed by MNI was better than NNI and NNI was better than CWQI, which was caused by parameter value and weight value, so we should not only stick to a certain assessment method, but also need to comprehensively consider the purpose of evaluation.

1. Introduction

Freshwater resource is indispensable resource for human beings, and the total amount of freshwater resource in China is relatively scarce. Therefore, the development and protection of them is very important [1]. Some surveys have shown that there are a large number of diseases caused by water pollution in poverty-stricken areas in China and the excessive pollutants in the groundwater are related to human activities [2][3]. As a large-scale agricultural irrigation area, the Jinghui canal irrigation area has critical groundwater pollutions due to the strong agricultural activities [4], so the assessment of groundwater quality is necessary in this area.

The single factor index method, the comprehensive water quality index method, the Nemerow index assessment method and fuzzy assessment method are extremely widespread in water quality assessment [5][6][7]. Among the above method, the single factor index method is the simplest, and the fuzzy assessment method is the most troublesome. Moreover, The Nemerow index assessment method and the comprehensive water quality index method only pay attention to the maximum and average values of the factors, and do not consider the weight of the factors. Therefore, it is essential to use the weights to correct the Nemerow index assessment method [8].
This paper used statistical analysis to analyze the basic water environment in Jinghui canal, and used the comprehensive water quality index method, the normal Nemerow index method and the modified Nemerow index method to evaluate the water quality of the Jinghui canal irrigation area, and compare the differences among different methods. The study results not only provide the water quality assessment result in the study area, but also recognize the gap among different water quality assessment methods.

2. Materials and methods

2.1. Study area and samples

The Jinghui canal irrigation area is located in the Guanzhong Plain of Shaanxi Province which surrounded by Jingyang County, Sanyuan County, Gaoling County and Fuping County, Lintong District and Yanliang District [4]. It is about 70km long, 20km wide, with an area of about 1180km² and an effective irrigation area of 900km². In this area, the average annual precipitation is 512.5mm, and the annual average temperature is 13.1-13.4 °C. Alluvial terraces and loess tablelands are main geomorphological types in this irrigation area [4]. And the recharge in irrigated areas is mainly meteoric precipitation, surface irrigation water supply, channel leakage supply. The overall flow direction of phreatic groundwater is basically consistent with the topographic trend, which is NW-SE. The drainage in irrigation area is vertical and horizontal, and the drainage in irrigation areas is mainly in the form of vertical discharge, supplemented by horizontal discharge.

In this study, 47 shallow groundwater samples were collected from unconfined aquifers in Jinghui canal irrigation area (Figure 1) during November 2009 and pH, total dissolved solids (TDS), total hardness (TH), major ions, nitrogen, and heavy metal were measured in laboratory.

![Figure 1](image-url)
2.2. Water quality index method

2.2.1. The comprehensive water quality index method. The comprehensive water quality index method (CWQI) is one of the most common methods in water quality assessment. It not only calculated maximum value of pollutants but also took other factors into considered. The formula is as follows [6]:

\[
CWQI = \sqrt{\frac{Q_{\text{max}}^2 + (Q_{\text{ave}})^2}{2}}
\]

Where, \(Q_i\) is the score of each assessment factor, \(Q_{\text{max}}\) is the maximum value of each factor score, \(Q_{\text{ave}}\) is the average value of factor score, \(n\) is the number of factors. The score table is as follow (Table 1):

| level | \(Q_i\) | level | \(Q_i\) |
|-------|--------|-------|--------|
| I     | 0      | IV    | 6      |
| II    | 1      | V     | 10     |
| III   | 3      |       |        |

2.2.2. The normal Nemerow index assessment method. The normal Nemerow index assessment method (NNI) is similar to CWQI, but the value of evaluation parameter are different. The formula is as follows:

\[
N_{\text{normal}} = \sqrt{\frac{N_{\text{max}}^2 + (N_{\text{ave}})^2}{2}}
\]

\[
N_i = \frac{C_i}{S_i}
\]

Where, \(C_i\) represents the measured concentration of each factor, \(S_i\) indicates the standard concentration of each factor (Table 2), \(N_i\) is Nemerow index, \(N_{\text{max}}\) is the maximum value of Nemerow index, \(N_{\text{ave}}\) is the average value of Nemerow index.

2.2.3. The modified Nemerow index assessment method. The modified Nemerow index assessment method (MNI) considered the weight of each factor in the assessment process. The formula is as follows [6]:

\[
N_{\text{modified}} = \sqrt{\frac{N_{\text{max}}^2 + (N_{\text{ave}})^2}{2}}
\]

\[
N_{\text{ave}} = \sum L_i N_i
\]

\[
L_i = \frac{S_{\text{max}}}{\sum S_{\text{max}} S_i}
\]

\[
N_{\text{ave}} = \frac{S_{\text{max}}}{\sum S_{\text{max}} S_i}
\]

Where, \(S_{\text{max}}\) is maximum value of standard concentration, \(S_i\) is standard concentration of each factor, \(L_i\) is the weight of each Nemerow index, \(N_i\) is Nemerow index, \(N_{\text{max}}\) is the maximum value of Nemerow index, \(N_{\text{ave}}\) is the modified value of Nemerow index.
3. Results and discussion

3.1. Physicochemical assessment

It can be seen from Table 2 that pH, Pb and As of the jinghui canal were under the standard limit given by the WHO. And other parameters were exceeded the standards, such as, TH was 350.4 – 1320.1 mg/L and TDS was 874.1 – 4285.1 mg/L. This might be due to the water-rock interactions and evaporation in the area [9]. NO₃⁻, NO₂⁻, NH₄⁺ and Cr⁶⁺ were in the range of 0 – 82.8 mg/L, 0 – 0.15 mg/L, 0 – 3.52 mg/L and 0 – 0.26 mg/L, respectively. This might due to industrial and agricultural irrigation activities in the area [4]. Therefore, it is very necessary to evaluate the water quality related to nitrogen and heavy metals in this area.

Table 2. Descriptive statistics of water quality variables of sampling sites of Jinghui canal.

| Index | Unit | Maximum | Minimum | Mean | National standard |
|-------|------|---------|---------|------|------------------|
| pH    |      | 8.48    | 7.14    | 7.76 | 6.5-8.5          |
| TH    | mg/L | 1320.1  | 350.4   | 815.98 | 450              |
| TDS   | mg/L | 4285.1  | 874.1   | 1868.03 | 1000             |
| NO₃⁻  | mg/L | 82.8    | 0       | 28.51 | 20               |
| NO₂⁻  | mg/L | 0.15    | 0       | 0.01  | 0.02             |
| NH₄⁺  | mg/L | 3.52    | 0       | 0.11  | 0.2              |
| Pb    | mg/L | 0.003   | 0       | 0.0019 | 0.05              |
| As    | mg/L | 0.02    | 0       | 0.01  | 0.05             |
| Cr⁶⁺  | mg/L | 0.26    | 0       | 0.04  | 0.05             |

3.2. Water quality assessment based on water quality index (WQI)

Water quality of jinghui canal irrigation area was assessed by the comprehensive water quality index (CWQI) method, the normal Nemerow index assessment method (NNI) and the modified Nemerow index assessment method (MNI) regarding NO₃⁻, NO₂⁻, NH₄⁺, Pb, As and Cr⁶⁺. Water quality standard is shown in Table 3.

Table 3. Water quality assessment standard in different method [6].

| Method  | Grade I | Grade II | Grade III | Grade IV | Grade V |
|---------|---------|----------|-----------|----------|---------|
| CWQI    | 0-0.8   | 0.8-2.5  | 2.5-4.25  | 4.25-7.2 | >7.2    |
| N_modified | 0-0.59 | 0.59-0.75 | 0.75-1   | 1-3.96  | >3.96   |
| N_normal | 0-0.56 | 0.56-0.68 | 0.68-1   | 1-4.2   | >4.2    |

The assessment results were shown in Table 4. There are 47 sampling points in the area, and in the comprehensive index method, 2 areas were divided into Grade I, 10 areas were divided into Grade II, 0 area was divided into Grade III, 15 areas were divided into Grade IV, and 20 areas into Grade V, accounting for 4.1%, 21%, 0%, 31.9% and 43% of the total sample, respectively. While in the normal Nemerow index assessment method, there were 7 areas for Grade I, 5 areas for Grade II, 4 areas for Grade III, 28 areas for Grade IV, and 2 areas for Grade V, and in the modified Nemerow index assessment method, there were 8 areas for Grade I, 5 areas for Grade II, 5 areas for Grade III, 28 areas for Grade IV, and 2 areas for Grade V, between NNI and MNI, the water quality results are mostly Grade IV, accounting for 59.5% of the total area. It can be seen that the groundwater pollution in the jinghui canal is serious and it is not suitable for drinking and irrigation, the reason of this phenomenon might be the industrial activities and agricultural irrigation. There’s also some study shown that the
agricultural problems in jinghui canal were more serious, and the human health risk caused by nitrogen is also high, which needs attentions and treatments [4].

| Table 4. Water quality classification of Jinghui canal irrigation area based on WQI values. |
| Number | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|--------|---|---|---|---|---|---|---|---|---|---|
| CWQI   | II | II | IV | IV | V | IV | V | V | I | II |
| N_{modified} | I | II | IV | IV | IV | II | V | IV | I | II |
| N_{normal} | I | II | IV | IV | IV | III | V | IV | I | II |
| Number | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| CWQI   | IV | V | V | V | I | V | V | IV | IV | II |
| N_{modified} | III | IV | IV | IV | I | IV | IV | IV | IV | I |
| N_{normal} | III | IV | IV | IV | I | IV | IV | IV | I | II |
| Number | 21 | 22 | 23 | 24 | 25 | 26 | 27 | 28 | 29 | 30 |
| CWQI   | IV | V | V | V | I | V | V | IV | IV | II |
| N_{modified} | IV | IV | IV | IV | III | I | I | IV | II |
| N_{normal} | IV | IV | IV | IV | III | I | I | IV | II |
| Number | 31 | 32 | 33 | 34 | 35 | 36 | 37 | 38 | 39 | 40 |
| CWQI   | IV | II | V | V | V | V | V | IV | V | V |
| N_{modified} | III | I | IV | IV | IV | V | IV | IV | IV |
| N_{normal} | III | II | IV | IV | IV | III | I | I | IV | II |
| Number | 41 | 42 | 43 | 44 | 45 | 46 | 47 |
| CWQI   | IV | V | IV | II | IV | II | V |
| N_{modified} | IV | IV | IV | I | III | II | IV |
| N_{normal} | IV | IV | IV | I | III | II | IV |

3.3. Comparison of different methods
Among CWQI, NNI and MNI, the water quality assessment results under this three methods were poor which unsuitable for drinking and irrigation (Figure 2), but in CWQI, the water quality was poorer than the other two methods, its mainly IV, V grade water. And the water quality assessed by MNI and NNI were better, its mostly concentrated on grade IV, this might mainly due to the difference in parameter values and standard divisions of different methods. Besides, water quality by MNI was better than NNI, the reasons are as follow:

![Figure 2. The proportion of water quality grades in different method.](image)
In MNI, the results were more targeted, the method considers the weight of pollutant ion damage and used $N_{w_{av}}$ replaced $N_{w_{re}}$, the weight assignment of this paper was shown in Table 5. It can be seen that $NO_2^-$ is the most harmful pollutant in jinghui canal, followed by Pb, As and $Cr^{6+}$, finally $NH_4^+$ and $NO_3^-$. Since the pollutants in the area were mainly $NO_3^-$ which has low weight (Table 5), thus the $NO_3^-$ effect was weakened, $NO_2^-$ and heavy metal were strengthened, the water quality calculated by MNI was better in some areas. In conclusion, in the process of water quality assessment, we should not only stick to a certain assessment method, but also need to comprehensively consider the purpose of evaluation and the significance of evaluation, finally select appropriate evaluation methods.

| Contaminant | $NO_3^-$ | $NO_2^-$ | $NH_4^+$ | Pb | As | $Cr^{6+}$ |
|------------|---------|---------|--------|----|----|---------|
| $\omega$   | 0.0004  | 0.431   | 0.043  | 0.174 | 0.174 | 0.174 |

4. Conclusions

Through statistical analysis, it was found that there were nitrogen and heavy metal pollution in Jinghui canal irrigation area, and the water quality in this area is mainly assessed as grade IV and grade V by CWQI, accounting for 31.9% and 43% of the whole area, respectively. And in MNI and NNI, there was 59.5% of water samples were assessed as grade IV. Therefore, it can be seen that the pollution in the Jinghui canal is serious.

In addition, the water quality asessed by CWQI was poorer than NNI and NNI was poorer than MNI, and the NNI method is more targeted. This is due to the different weight, parameter values and classification basis of different methods. Therefore, in the water quality assessment, different method need to be selected according to different purposes.

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