Health Risk Assessment Model Based on Close Degree of Modified Interval Number and Its Application

Yumin Wang

School of Energy and Environment, Southeast University. Nanjing, 210096

Abstract. Health risk described relationship between water quality and body health quantitatively. In this paper, health risk assessment model based on close degree of modified interval number was developed aiming to solve the uncertainty problem that parameters in health risk assessment were almost expressed as interval numbers. The model was applied to two surface water sources to assess and compare their health risks. The results indicated that the risks of two water sources were all at level III, and the health risk of water source 2 was higher than water source 1. This model could utilize the uncertain information of parameters sufficiently to acquire reliable and objective results.

1. Introduction

Health risk assessment (HRA) emerged in the 1980s. Its main purpose is to quantitatively assess the risk of some harmful environmental factors on human health [1]. However, drinking water is an important way for toxic substances to affect human health [2-3]. By assessing the water environment health risk of drinking water source, we can make clear the types of pollutants that are at risk to human health, and provide scientific basis for drinking water safety [4-5].

Since uncertainties occurred in the water environment health risk assessment model, such as pollutant concentration, drinking water per capita, exposure frequency and so on, at present, the theory of dealing with uncertain information, such as rough set theory, fuzzy theory, grey theory, stochastic process, extension method and so on, has been applied to the water environment health risk assessment. In the literatures, Li proposed triangular fuzzy number [6-8], Zhu et al. combined concepts of interval number and membership degree [8]. Jin et al. established water environment risk model SS-TFN by coupling stochastic simulation and triangular fuzzy number [9]. Zhang et al. used Monte Carlo method to analyze the health risks caused by benzene pollution in various areas of an olefin plant near a water source through respiratory and drinking water exposure [1]. Zhang et al. used logistic chaos iterative sequence to improve Monte Carlo technology to obtain the environmental risk of reclaimed water in a sewage treatment plant [10]. Wu et al. established a water quality risk assessment model based on unascertained theory [11-12]. Zhou et al. assessed the health risk of drinking water comprehensively by the multi-attribute decision-making method [13].

In this paper, the environmental risk is divided into five intervals according to the domestic and foreign standards on water environment health risk. Using the evaluation method of pattern recognition for reference, we can judge the closeness between the health risk interval of water source and the improved interval number of a certain risk standard interval as the basis of evaluating the health risk level of the water source. We established a water environment health risk assessment model based on the improved interval number approach degree, which was applied to evaluate environmental health risk of two water sources in a city. In addition, the applicability and reliability of the model in water source health risk assessment are analysed.
2. Improved Interval Number Proximity Model Based on Uncertain Information Processing

2.1. Closeness of Interval Number

Assume \( R \) as real domain for \( a^- \), \( a^+ \in R \) and \( a^- \leq a^+ \), then \( a = [a^-, a^+] \) is termed as interval numbers, and all interval numbers are called as \( [R] \).

**Theory 1**

Suppose mapping \( N: [R] \times [R] \rightarrow [0,1] \), \( (a, b) \rightarrow N(a, b) \) for any \( a, b, c \in [R] \) satisfies conditions as follows:

1) \( N(a, b) = N(b, a) \);
2) \( N(a, b) = 1 \Leftrightarrow a = b \) and \( N(a, \emptyset) = 0 \);
3) When \( a \subseteq b \subseteq c \) (i.e., \( c^- \leq b^- \leq a^- \leq a^+ \leq b^+ \leq c^+ \)), \( N(a, c) \leq N(a, b) \) and \( N(a, c) \leq N(b, c) \), \( N \) is termed as closeness function for interval between \( a \) and \( b \) [14-15].

**Definition 1**

Assume two interval numbers \( a = [a^-, a^+] \), \( b = [b^-, b^+] \), and \( a, b \in [R] \), the closeness function between interval numbers of \( a \) and \( b \) can be described by Eq. (1) as follows [16].

\[
N(a, b) = \begin{cases} 
\frac{1}{\sqrt{1 + d(a, b)}}, & d(a, b) \in [0,1) \\
0, & d(a, b) \geq 1 
\end{cases}
\]

Where \( d(a, b) = \left( \frac{a^- + a^+ - b^- + b^+}{2} \right)^2 + \frac{1}{12} (a^+ - a^- - b^+ - b^-)^2 \). It can be verified that \( d(a, b) \) can satisfy the condition of Theory 1[17].

2.2. Health Risk Assessment Model Based on Closeness Degree

According to the chemicals classification by the International Cancer Research Center (IARC) and the World Health Organization (WHO), toxic pollutants in water are divided into chemical carcinogens as well as non-carcinogenic chemical toxic substances (non-carcinogens). Chemical carcinogens belong to class 1 (sufficient evidence of carcinogenicity to human body) and class 2 group A (limited evidence of carcinogenicity to human body, but sufficient evidence of carcinogenicity to animals). The health risk assessment model of chemical carcinogens is shown by Eq. (2) expressed as follows.

\[
R^c = \sum_{j=1}^{J} R^c_j = \sum_{j=1}^{J} \left[ 1 - \exp \left( \frac{-Q \times C_j / W \times q_j}{Y} \right) \right] / Y 
\]

Where \( R^c_j \) is the average annual risk of personal carcinogenesis caused by chemical carcinogens \( j (j = 1,2,...,J) \) through drinking water, \( a^+ \); \( Q \) is average daily drinking water intake by adults, L; \( C_j \) is the mass concentration of chemical carcinogens, mg/L; \( W \) is human mass, kg; \( q_j \) is carcinogenic intensity coefficient estimated for chemical carcinogens through drinking water route, mg/(kg·d) (Table 1); \( Y \) is personal life, a. In the water environment risk assessment model, the concentration of pollutants, daily drinking water intake and human body quality are all uncertain, and the uncertainty can be described by interval number \( x = (x^-, x^+) \). As such, the health risk range of chemical carcinogens \( R^c \) can be expressed by Eq. (3) as follows.

\[
R^c = \sum_{j=1}^{J} \frac{1 - \exp (Q \otimes C_j \Delta W \otimes q_j)}{Y} 
\]
The detailed operation rules of interval numbers can be found in literatures [8].

Table 1. Value of model parameter $q_j$.

| Chemical carcinogens | As | Cr$^{6+}$ |
|----------------------|----|-----------|
| $q_j$ (mg/kg·d)     | 15 | 41        |

The health risk assessment model of non-carcinogenic chemical toxic substances is shown by Eq. (4).

$$R^e = \sum_{k=1}^{K} R_k^e = \sum_{k=1}^{K} \left( Q \times C_j \times 10^{-6} / W / RfD_k / Y \right)$$

(4)

Where $R_k^e$ is the average annual risk of personal carcinogenesis caused by non-carcinogenic chemical toxic substance $k$ through drinking water, a-1; $RfD_k$ is the reference dose estimated by drinking water route for non-carcinogenic chemical toxic substance $k$, mg/(kg·d), shown in Table 2.

Table 2. Value of model parameter $RfD_k$.

| Non-carcinogenic substance | NH$_4^+$ | Fluoride | Cu | Mn | Nitrate | Zn | Fe |
|----------------------------|----------|----------|----|----|---------|----|----|
| RfD$_k$(mg/kg·d)           | 0.97      | 0.06     | 0.14 | 1.6 | 0.3     | 0.3 |    |

The health risk interval of non-carcinogenic chemicals $R^e$ can be expressed by Eq. (5) as follows.

$$R^e = \sum_{k=1}^{K} Q \otimes C_j \times 10^{-6} / W \times RfD_k / Y$$

(5)

Assume that the toxic effects of various toxic pollutants on human health can be iterative, the general model of interval assessment of water environment health risk can be expressed by Eq. (6) as follows.

$$R = R^c + R^e$$

(6)

2.3. Classification of Environmental Health Risk Assessment

According to various risk levels and their acceptability, the risk assessment standard interval can be divided into six grades, as shown in Table 3 [15].

Table 3. Classification of assessment standard.

| Risk level | Standard interval($\times 10^{-6}$) | Improved interval | Danger       | Acceptance    |
|------------|-----------------------------------|-------------------|--------------|---------------|
| I          | [1,10]                            | [-6,-5]           | Lower        | Acceptable    |
| II         | [10,100]                          | [-5,-4]           | Low          | Accept reluctantly |
| III        | [100,500]                         | [-4,-3.3]         | Common       | Difficult to accept |
| IV         | [500,1000]                        | [-3.3,-3]         | higher       | Hard to accept |
| V          | [1000,5000]                       | [-3,-2.3]         | high         | Unacceptable  |

2.4. Water Source Health Risk Assessment Model Based on Improved Interval Number Closeness Degree

Since the environmental risk assessment is too small, the closeness degree of calculated health risk interval number to the classification interval is too small, which makes it unable to measure the level of environmental risk assessment accurately. As such, logarithm is applied to improve the health risk
assessment interval and assessment classification interval to obtain improved intervals. The improved
closeness degree based on intervals is calculated by Eq. (1), which can judge the water environment
risk assessment grade

3. Application

3.1. Case Study
In a certain city, there are two surface drinking water sources. The water samples were taken once a
month with the analysis method of <<The standard test method for drinking water (GB / T5750-2006).
The minimum value and maximum value of each chemical carcinogen and non-carcinogenic chemical
toxic substance correspond to the lower limit and upper limit of parameter interval, respectively. The
 statistical intervals of the chemical carcinogen and non-carcinogenic chemical toxic substance are
 shown in Table 4.

Table 4. Monitoring data of water quality in drinking water source.

| Source/Index | As       | Cr$^{6+}$ | NH$_4^+$ | Fluoride | Cu       |
|--------------|----------|-----------|----------|----------|----------|
| Water source 1 | [0.002,0.006] | [0.004,0.038] | [0.13,4.21] | [0.38,1.00] | [0.02,0.03] |
| Water source 2 | [0.002,0.004] | [0.005,0.053] | [0.029,0.48] | [0.42,0.95] | 0.02,0.09 |

| Source/Index | Mn | Nitrate | Zn | Fe |
|--------------|----|---------|----|----|
| Water source 1 | [0.01,0.27] | [0.009,2.26] | [0.06,0.11] | [0.05,0.68] |
| Water source 2 | [0.01,0.32] | [0.1,1.2] | [0.05,0.06] | [0.05,0.44] |

3.2. Health Risk Assessment Interval
According to the corresponding literature, the interval of daily drinking water for adults is [1.5 3], and
the interval of adult average weight is [45 85], as such, Environmental health risk assessment $R$ can
be obtained by Eqs. (3) - (6), shown in Table 5.

Table 5. Health risk assessment zone of water sources $R$.

| Source/Index | As ($\times 10^{-5}$) | Cr$^{6+}$ ($\times 10^{-5}$) | NH$_4^+$ ($\times 10^{-10}$) | Fluoride ($\times 10^{-10}$) | Cu ($\times 10^{-10}$) |
|--------------|----------------------|-----------------------------|-----------------------------|-----------------------------|----------------------|
| Water source 1 | [1.4,4.0] | [7.3,68.3] | [0.6,19.5] | [28.4,74.8] | [18,26.9] |
| Water source 2 | [1.4,2.7] | [9.2,94.3] | [0.1,2.2] | [31.4,71.1] | [18,81] |

| Source/Index | Mn ($\times 10^{-10}$) | Nitrate ($\times 10^{-10}$) | Zn ($\times 10^{-10}$) | Fe ($\times 10^{-10}$) | Total risk ($\times 10^{-4}$) |
|--------------|------------------------|-----------------------------|------------------------|------------------------|-----------------------------|
| Water source 1 | [0.3,8.7] | [0.02,6.34] | [0.9,1.7] | [0.7,10.2] | [0.9,7.2] |
| Water source 2 | [0.3,10.3] | [0.3,3.4] | [0.7,0.9] | [0.7,6.6] | [1.1,9.7] |

3.3. Health Risk Assessment Grade Based on the Closeness Degree of Improved Intervals
The health risk assessment grades based on closeness degree of improved intervals the improved
intervals are calculated by Eq. (1), and shown in Table 6.
Table 6. Definition of health risk assessment gradation.

| Closeness degree of improved intervals | I    | II   | III  | IV   | V    | Grade |
|---------------------------------------|------|------|------|------|------|-------|
| Water source 1                        | 0.59 | 0.73 | 0.96 | 0.82 | 0.72 | III   |
| Water source 2                        | 0.58 | 0.71 | 0.92 | 0.85 | 0.74 | III   |

4. Conclusions
In this paper, a health risk assessment model based on the improved intervals closeness is proposed and applied to two water sources in a certain city. The results indicated that the health risks of water sources in the city are at level III. In addition, the closeness of the improved interval to level IV in water source 2 is greater than that in water source 1, which indicated that the health risk level of water source 2 is higher than water sources 1. This model provides a new way to assess the risk of water environment health effectively, and it is easy to be understood and applied practically.

Acknowledgement
This work was funded by Water Pollution Control Project in Taihu (Grant No. TH2018403). This work was funded by Jiangsu Overseas Visiting Scholar Program for University Prominent Young & Middle-aged Teachers and Presidents (2017).

References
[1] Yinghua, Z., et al., Uncertainty analysis of health risk assessment caused by benzene contamination in a contaminated site. Environmental Science, 2007. 28(7): p. 1409-1415.
[2] Xibang, H., et al., Integrated fuzzy model based on interval number for the assessment of environmental health risk of drinking water resources. Environmental Science and Technology, 2012. 35(121): p. 349-355.
[3] Huiping, L., et al., Water environmental risk assessment of drinking water source area of Taizhou Third Waterworks. Journal of Hohai University (Natural Sciences), 2015. 43(2): p. 114-120.
[4] Dragan Pamucar, Ivan Petrovic, Goran Cirovi. Modification of the Best–Worst and MABAC methods: A novel approach based on interval-valued fuzzy-rough numbers. Expert Systems with Applications 2018, 91, 89-106.
[5] Xiao Liu, Ping Guo, Qian Tan, Jingfeng Xin, Yifan Li, Yikuan Tang. Drought risk evaluation model with interval number ranking and its application. Science of The Total Environment 2019, 685, 1042-1057.
[6] Ruzhong, L., Assessment for environmental health of urban water supply source based on uncertain information. Shuili Xuebao, 2007. 38(8): p. 895-900.
[7] Ruzhong, L., Study on fuzzy model for water environmental health risk assessment. Journal of North University of China (Natural Science Edition), 2009. 30(5): p. 443-449.
[8] Huina, Z., et al., An integrated fuzzy model based on interval numbers for assessment of environmental health risks of water sources. Acta Scientiae Circumstantiae, 2009. 29(7): p. 1527-1533.
[9] Juliang, J., W. Kaiya, and L. Ruzhong, Coupling method of stochastic simulation with triangular fuzzy numbers for water environment risk assessment. Shuili Xuebao, 2008. 39(11): p. 1257-1266.
[10] Jianlong, Z., et al., Health risk assessment in the reuse of reclaimed water based on improved Monte Carlo method. Acta Scientiae Circumstantiae, 2010. 30(11): p. 2353-2360.
[11] Yifeng, W., X. Lianqing, and L. Xiwu, Assessment model of water quality risk based on unascertained mathematics theory. Acta scientiae Circumstantiae, 2006. 26(6): p. 1047-1052.
[12] Fuming, G., W. Yifeng, and Q. Zhuojie, *Environmental health risk assessment for carcinogenic pollutants based on uncertainty theory*. Water Resources and Power 2006. 24(5): p. 5-8.

[13] Rongxi, Z., F. Fuyun, and Y. Xiaojin, *Comprehensive assessment of health risk to drinking water based on multi-attribute making*. Environmental Science and Management, 2011. 36(3): p. 158-162.

[14] Huawen, L., *Ranking fuzzy numbers based on a distance measure*. Journal of Shandong University, 2004. 39(2): p. 30-36.

[15] Chunling, Y., Z. Chuanfang, and X. Wencui, *A model based on similarity degree of interval number for uncertain multi-attribute decision making*. Mathematics in Practice and Theory, 2010. 40(21): p. 148-154.

[16] Rui, T. and Z. Yixin, *Application of health risk assessment model on water environment safe evaluation*. Environmental Science Survey, 2011. 30(3): p. 86-89.

[17] Yue, B., G. Li, and L. Guofeng, *A study of water environment quality evaluation model based on interval number closeness*. Mathematics in practice and theory, 2014. 44(8): p. 34-41.