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Research Article

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Study on water quality evaluation methods of water supply network

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ABSTRACT

Fuzzy mathematical evaluation model and comprehensive index model are used separately to the water quality evaluation of partial water supply network of a city in southern part of our country. The evaluation result shows that the fuzzy mathematical evaluation method is characterized by good accuracy and simple operation; comprehensive index method possesses some advantages in directviewing evaluation results and higher precision. From the evaluation results in this case, the comprehensive index evaluation method is more reasonable than the fuzzy mathematics evaluation method.

Keywords: Water quality evalution; Fuzzy mathematics evaluation method; Comprehensive index method; Water quality of pipe network

INTRODUCTION

With the rapid development of economy as well as the improvement of people's living standard, water supply security problems are becoming increasingly serious[1]. It is not only closely related to the development of society and economy, but also to human life and health. Thus how to safeguard the water supply security has been an important issue we face.

The water quality needs to be evaluated accurately and objectively in order to ensure the security of water supply. The main objects of water quality assessment are the water quality of finished water, pipe network water and user side. Thereinto, the water supply network is easy to cause secondary pollution because of its long route and wide coverage, and then it will affect the water quality. So carring out a comprehensive evaluation of the water quality of pipe network is the important and basic work to ensure the security of water supply, and only by evaluating the monitoring data of water supply network reasonably can we provide a scientific basis for it.

2. Water quality assessment methods of pipe network

Currently, the most widely-used water quality assessment methods include single-factor evaluation, pollution index, fuzzy mathematics evaluation, gray system evaluation, analytic hierarchy process, matter element analysis, artificial neural network evaluation and water quality identification index, etc. Each of these methods have their own characteristics, because of the water quality of pipe network itself a fuzzy system that is multifactorially controlled, complex, and nonlinear, simultaneously how to determine the rank division, the evaluation standard and methods of various projects is fuzzy[2]. The fuzzy evaluation method can carry on quantitative processing for water quality, while the comprehensive index method has some advantages in directviewing evaluation results and higher precision[3]. Therefore, both methods were choosed in this paper, and the evaluation results were compared.

3. The basic information and data of water quality of water supply network in a city of southern China

According to the pipe network water quality monitoring data of waterworks in the city, eight indexes as total bacteria count, turbidity, color, iron, manganese, residual chlorine, stink and smell and total coliforms are selected as evaluation parameters. Water quality evaluation was made by taking 2008 data of two water supply network monitoring points B11 and B18 for example. The water quality of them was expressed in table 1.

4. Water quality evaluation by the method of fuzzy mathematics

Fuzzy mathematics method establishes its membership function by setting up evaluation factor and judgment sets; then build single factor fuzzy evaluation matrix according to the weighting sets which are determined through expert scoring method, thus different assessment degree of every evaluation factor belongs to a evaluation class set can be determined, and it is also called membership grade, shown by r_{ij}.

Table1. The monitoring data of points B11 and B18 in 2008

Monitoring time	Monitoring point	Total bacteria count /(CFU/mL)	Turbidity /NTU	Color /CU	Fe /(mg/L)	Mn /(mg/L)	Residual chlorine /(mg/L)	Stink and smell	Total coliforms /(CFU /100mL)
2008.02	B11	0	0.95	12	0.19	0.05	1.1	Faint	0
2008.03	B11	0	0.5	10	0.06	0.05	1	None	0
2008.04	B11	0	0.2	10	<0.02	0.04	0.9	None	0
2008.06	B11	0	0.2	10	<0.02	0.1	0.3	Faint	0
2008.09	B11	6	0.15	10	<0.02	<0.02	1.52	Faint	0
2008.10	B11	1	0.1	8	<0.02	0.02	1.52	Faint	0
2008.11	B11	9	0.25	12	0.02	0.07	1.76	Faint	0
2008.12	B11	0	0.2	10	<0.02	0.06	1.97	None	0
2008.02	B18	0	0.2	10	0.02	0.03	1.3	None	0
2008.03	B18	1	0.2	10	0.04	0.09	1	Faint	0
2008.04	B18	0	0.25	10	0.02	0.08	1	None	0
2008.06	B18	0	0.25	12	<0.02	0.05	1.3	None	0
2008.07	B18	0	0.2	10	<0.02	0.04	1.25	None	0
2008.09	B18	0	0.25	10	<0.02	<0.02	1.62	Faint	0
2008.10	B18	0	0.2	10	〈0.02	0.02	1.81	None	0
2008.11	B18	0	0.15	10	<0.02	0.02	1.55	Faint	0
2008.12	B18	0	0.2	10	〈0.02	0.05	1.51	Faint	0

4.1 Establishment of factor sets

According to current national Standards for drinking water quality(GB5749-2006), if Escherichia coli is detected, the water quality will be deemed to be unqualified; then establish factor sets for the seven parameters of total bacteria count,turbidity, color, iron, manganese, residual chlorine, stink and smell, and taking the B11 monitoring point data which was monitored in February for example, its factor set is : U= {0,0.95,12,0.19,0.05,1.1, faint}.

4.2 Establishment of judgment sets

Establish a judgment sets according to current national *Standards for dringking water quality*(GB5749-2006) and *Water quality standards for fine drinking water*(CJ94-2005), and that is V = {excellent, good, qualified, poor, bad}. In this paper, the values in the judgment set matrix row are respectively classification standard values of seven evaluation parameters, specifically for equation (1):

$$V=\begin{bmatrix} Totalbacteriacount & 20 & 50 & 100 & 150 & 200 \\ \text{Turbidity} & 0.3 & 0.5 & 1 & 2 & 3 \\ Color & 5 & 10 & 15 & 22.5 & 30 \\ Fe & 0.075 & 0.15 & 0.3 & 0.45 & 0.6 \\ Mn & 0.025 & 0.05 & 0.1 & 0.15 & 0.2 \\ \text{Re}\,sidualchlorine & 0.3\sim0.8 & 0.3\sim0.8 & 0.3\sim0.8 & \prec 0.3, \succ 0.8 & \prec 0.3, \succ 0.8 \\ Stinkandsmell & None & Fa\,\text{int} & Weak & Obvious & Strong \end{bmatrix} \quad (1)$$

4.3 Determination of membership function

For the parameter which is greater value and heavy pollution, its membership function u_{ij} can be shown by the following equation (2):

$$\mu_{ij}(x_i)=\begin{cases} 1-\mu_{i,j-1}(x_i) & v_{i,j-1}<x_i\le v_{i,j} \\ \dfrac{v_{i,j+1}-x_i}{v_{i,j+1}-v_{i,j}} & v_{i,j}<x_i\le v_{i,j+1} \\ 0 & v_i>s_{i,j+1} \end{cases} \quad (2)$$

Where: x_i is the monitoring value of evaluation factor *I* ;

v_{ij} is the evaluation standard value of the factor *i* corresponding to level *j* ;

μ_{ij} is the membership grade of evaluation standard value of the factor *i* corresponding to level *j* ;

If $x_i \le v_{i1}$, then $\mu_{i1}(x_i) = 1$, other $\mu_{ij}(x_i) = 0$; If $x_i \ge v_{in}$, then $v_{in}(x_i)$ =1, other $\mu_{ij}(x_i) = 0$.

According to the membership function set of seven parameters, establishing corresponding fuzzy relationship matrix R. The fuzzy relationship matrix of above water supply network was shown by the following equation (3):

$$R = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 \\ 0 & 0.1 & 0.9 & 0 & 0 \\ 0 & 0.6 & 0.4 & 0 & 0 \\ 0 & 0.73 & 0.27 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.5 & 0.5 \\ 0 & 1 & 0 & 0 & 0 \end{bmatrix} \quad (3)$$

4.4 Determination of weighting sets

The expert scoring method was adopted to determine the weighting of each parameter in the water quality evaluation. The scoring results of these parameters have been given by dozens of experts in the area and related fields through letters and $E - mail$ in the first period. According to the results, the weighting of each parameter can be obtained, after normalization, the row matrix of these parameters as follows:

B=[0.1489，0.14957，0.13295，0.12542，0.13184，0.16175，0.14957]

4.5 Calculation of membership grade

The evaluation result of B11 monitoring water quality can be calculated through the fuzzy matrix compound operation, and it can be shown as follows:

$r_{ij} = B \times R$ = [0.1489，0.467694，0.221656，0.080875，0.080875]

It adopts maximum principle of membership grade in water quality assessment to determining the water quality, so the fuzzy evaluation result of B11 is “good”. Similarly, all the results can be calculated. The results of two monitoring points B11 and B18 were expressed in table 2.

Table2. The results of fuzzy mathematical evaluation of B11 and B18

Monitoring time	Monitoring point	Excellent	Good	Qualified	Poor	Bad	Water quality
2008.02	B11	0.1489	0.467694	0.221656	0.080875	0.080875	Good
2008.03	B11	0.42389	0.41436	0	0.080875	0.080875	Excellent
2008.04	B11	0.626196	0.212054	0	0.080875	0.080875	Excellent
2008.06	B11	0.42389	0.28252	0.13184	0	0	Excellent
2008.09	B11	0.55573	0.28252	0	0.080875	0.080875	Excellent
2008.10	B11	0.60891	0.22934	0	0.080875	0.080875	Excellent
2008.11	B11	0.42389	0.308444	0.105916	0.080875	0.080875	Excellent
2008.12	B11	0.57346	0.238422	0.026368	0.080875	0.080875	Excellent
2008.02	B18	0.678932	0.159318	0	0.080875	0.080875	Excellent
2008.03	B18	0.42389	0.308888	0.105472	0.080875	0.080875	Excellent
2008.04	B18	0.57346	0.185686	0.079104	0.080875	0.080875	Excellent
2008.06	B18	0.57346	0.21161	0.05318	0.080875	0.080875	Excellent
2008.07	B18	0.626196	0.212054	0	0.080875	0.080875	Excellent
2008.09	B18	0.55573	0.28252	0	0.080875	0.080875	Excellent
2008.10	B18	0.7053	0.13295	0	0.080875	0.080875	Excellent
2008.11	B18	0.55573	0.28252	0	0.080875	0.080875	Excellent
2008.12	B18	0.42389	0.41436	0	0.080875	0.080875	Excellent

5. Water quality evaluation by the method of comprehensive index

Until now, more than ten computation modes of comprehensive index method have come out, and they have their own characteristics[4]. A new comprehensive index evaluation method has been mentioned in some literature, and that is the conversion index method which was put forward by Li Fanxiu[5] ,Wang Wenqiang[6] and so on.This method refers to the five classification principle of *Surface water environment quality standard*(GB3838-2002), and first defines the conversion index: $r_i=s_{imax}- s_{imin}$, Where,$s_{imax}$is the maximum limit of *i* in the standard , and s_{imin} is the possible minimum value, assuming s_{imin}=0. Then each classification limit of all evluation parameters divided by r_i is taken as normalized limits, which can be used as "sub-indexes", and calculate each classification comprehensive index according to a certain mode; use the same index evaluation mode to calculate actual monitering comprehensive index; at last, the evaluation classification can be determined after comparing it with each classification.

According to the judgment set (1), each classification index value of all factors can be calculated by the above method, and all the classification comprehensive indexes of pipe network water quality grade standard are: I_1=12.33, I_2=25, I_3=46.67, I_4=73.33, I_5=100, namely dividing the degree rank standard of pollution by using the comprehensive indexes as shown in table 3. Calculate the comprehensive indexes and the evaluation results of monitoring data in Table 1 by the above method, and the results were shown in table 4.

Table3. The degree rank standard of pipe network water pollution

Comprehensive index	Classification
$0 \leq I_h < 12.33$	Excellent
$12.33 \leq I_h < 25$	Good
$25 \leq I_h < 46.67$	Qualified
$46.67 \leq I_h < 73.33$	Poor
$73.33 \leq I_h < 100$	Bad

Table4. The results of comprehensive index evaluation of B11 and B18

Monitoring time	Monitoring point	Comprehensive index	Water quality
2008.02	B11	25.67	Qualified
2008.03	B11	17	Good
2008.04	B11	12.67	Good
2008.06	B11	18.67	Good
2008.09	B11	10.93	Excellent
2008.10	B11	8.77	Excellent
2008.11	B11	18.23	Good
2008.12	B11	10.83	Excellent
2008.02	B18	11.67	Excellent
2008.03	B18	18.43	Good
2008.04	B18	17	Good
2008.06	B18	15.33	Good
2008.07	B18	12.67	Good
2008.09	B18	11	Excellent
2008.10	B18	10.67	Excellent
2008.11	B18	10	Excellent
2008.12	B18	13.67	Good

6. Analysis

It is concluded from above evaluation results that there are some differences in results between these two evaluation methods. This results from the different ideas of them, and fuzzy mathematics evaluation method emphasizes the general merits of fuzzy systems while comprehensive index method emphasizes the influence that exceeding factors on the results. The results of these two methods were shown in table 5:

Table5. The result of two evaluation methods to B11 and B18

Monitoring time	Monitoring point	Fuzzy mathematics evaluation method	Comprehensive index method
B11	2008.02	Good	Qualified
	2008.03	Excellent	Good
	2008.04	Excellent	Good
	2008.06	Excellent	Good
	2008.09	Excellent	Excellent
	2008.10	Excellent	Excellent
	2008.11	Excellent	Good
	2008.12	Excellent	Excellent
B18	2008.02	Excellent	Excellent
	2008.03	Excellent	Good
	2008.04	Excellent	Good
	2008.06	Excellent	Good
	2008.07	Excellent	Good
	2008.09	Excellent	Excellent
	2008.10	Excellent	Excellent
	2008.11	Excellent	Excellent
	2008.12	Excellent	Good

Comprehensive index method can integrate large amounts of environmental characteristic information by a simple mathematical formula, and can reflect the average level of environmental quality by simple values. Fuzzy mathematics evaluation method adopts the expert scoring method in weighting, and its main shortcoming is that the weight determination has some subjectivity, and furthermore it can not do a good-quality quantitative analysis for water quality. Comprehensive index method is more reasonable than fuzzy mathematics evaluation method by concluding from the results. Taking turbidity, color, iron, manganese four parameters for example, their monitoring values are closer to “good”, and its level defined as "good" is more reasonable in general, but the fuzzy mathematics evaluation method defined it as “excellent”.

CONCLUSION

In view of the whole evaluation process, comprehensive index evaluation method is a relatively simple way. It can make a quantitative description of the overall water quality, and can basically reflect the general nature and extent of water pollution as long as the projects, standards, and monitoring results are reliable, and the evaluation results are relatively satisfactory.

The membership functions of all water samples from partial water supply network of a city in southern part of our country were obtained by using fuzzy mathematics method. This method has considered the mutual connection and mutual influence of each parameter, and also has considered the fuzzy characteristics of water quality change, causing the evaluation results more comprehensive and reasonable. But fuzzy mathematics evaluation method needs to be further perfected and improved in practical application. There are still three problems in the fuzzy evaluation process: first, determination of weighting has some subjectivity by using the expert scoring method; second, when $x_i \geq v_{ij}$, the membership functions need further improvement and optimization; third, exceeding residual chlorine did not have a great impact on the final evaluation results. When carrying out water quality evaluation of pipe network, the establishment of comprehensive judgment set and weighting set should be considered carefully.

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