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Research Article

Application of Fuzzy Comprehensive Method in Water Quality Assessment of the Yongjiang River, China

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Abstract: In order to assess the water quality of the Yongjiang River, the annual samplings were taken in 13 sampling sites and physic-chemical environmental factors were analyzed. The assessment conclusion of fuzzy comprehensive method shows that water quality from all sampling sites in the Yongjiang River are as follows: Sites 1, 2, 13, 9, 11, 12, 5, 10, 8, 4, 7, 6 and 3 from excellent to inferior. The water quality reached Grade II and III at Site 1 and Site 2, respectively. Other sites were all in Grade V. If take seasonal change into consideration the assessment results were as follows: winter, spring, autumn and summer from excellent to inferior. It was Grade IV in winter and Grade V in other seasons. The results were basically consistent with the reports from different assessment methods in literature.

Keywords: Fuzzy comprehensive assessment, membership degree, matrix, water quality, Yongjiang River

INTRODUCTION

Quality assessment of water environment, i.e. water quality assessment, is an analysis on the environmental factors in a certain water body and makes the qualitative or quantitative evaluation for it. The assessment result could reveal the change pattern of water quality, realize the level of water pollution, find the sources of pollutant, pollution process and pollutant distribution. It can be used to explore the reasons of the change happened in water quality, predicate the trend of water quality and provide a scientific basis for the development, utilization, protection and management of water resources.

In basically, the water quality assessment is a process to describe the water quality quantitatively by some mathematical methods or technical means, or transform the quantity value into the evaluation comment. The monitoring data is the foundation of water quality assessment. By using the mathematical statistics and analysis, the representation value of numerical statistics and the environment could be obtained. And then, according to the evaluation method and the standard of water grade, water quality can be assessed. The quality of water environment includes three parts: water quality, aquatic organism and sediment. The contents of the assessment are involved more widely, including the temporal and spatial variations of water qualities in rivers, lakes and reservoirs, hydrobiological quality, sedimental environmental quality, nitrifications in lakes and reservoirs and overall comprehensive evaluation on the systems formed by these water bodies (Li, 1989; Cheng and Tan, 2002).

In terms of the Yongjiang River ecological system, there were some reports described the water quality status by studying on water physico-chemical indicators and biological indicators (WeiHong*et al*., 2013; Xianying*et al*., 2013; Zhang *et al*., 2013; Wang *et al*., 2014; Teng*et al*., 2014; Gong-Guo *et al*., 2015).

In this study, the water quality of the Yongjisng River was assessed by applying fuzzy comprehensive method based on the annual monitoring data of environmental factors.

LITERATURE REVIEW

The history of water environmental quality assessment in practice was more than 30 years. It has been made a great progress in the assessment theories and methods after many years of studies, developments and applications. So far, there are various methods with specifics for water quality assessment. There is a wide range of complexity and fuzziness in the qualitative and quantitative assessments of water quality. The fuzzy comprehensive assessment method, which is

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established in fuzzy mathematics principle, can reflect the water quality objectively and explain vague concepts and phenomena such as the degree of pollution and quality category. At present, this method has become a common method used in the quantitative study of water quality (Chang *et al*., 2001; Shu-Jun and Wan-Cun, 2007; Lian-Fang *et al*., 2006, Mingsheng *et al*., 2012; Jia*et al*., 2004; Lermontova*et al*., 2009; Jutao *et al*., 2010).

MATERIAL AND METHODS

Study area: The Yongjiang River is one of the seven major river systems in Zhejiang province, China (Li-Hua and Yi-Xin, 2004). There are two larger tributaries, Fenghua River and Yaojiang River, in the river system. Yaojiang River, with total length of 105 km and the basin area of 1934 km^2, originates from Xiajialing, Siming Mountain. Fenghua River, with 98 km long and a valley area of 2223 km^2, rises in Xiujian Hill, Siming Mountain. The water from Fenghua River and Yaojiang River converges in the centre of Ningbo City and flows into the East China Sea. Traditionally, the section of the Yongjiang River system that is formed after the convergence of the Fenghua and the Yongjiang branches is called the Yongjiang River and has a total length of 26 km, the basin area of 361 km^2. Just before Yaojiang River connects to Fenghua River, a dam was built in 1959. Since then, Yaojiang River has become a relatively static reservoir. For most of the year, Yaojiang River is closed or allows only a small amount of water to flow, due to the dam (Li-Hua and Yi-Xin, 2004). Therefore, the study area in this study included 124 km length and 2584 km^2 basin area. The main utilizations of water from the Yongjiang River system include drinking, agricultural irrigation, aquaculture, ship transportation and landscape.

Data collection: The data used in this study was taken from the samples collected annually (2011-2012) in the Yongjiang River. Table 1 shows the annual mean values of main physico-chemical factors measured at each sampling site.

Evaluation criteria: There were 5 phycico-chemical environmental factors chosen as the assessment indexes which were listed in "The Surface Water Environmental Quality Standard" (GB 3838-2002) (The National Standards Bureau, 2002). They were Dissolved Oxygen (DO), BOD_5, COD_{Mn}, Total Phosphorus (TP) and Total Nitrogen (TN) was and their limited values were used for later calculation (Table 2) as evaluation criteria.

With the standard values, a index set U = {DO, COD_{Mn}, BOD_5, TP, TN} was built up with 5 indexes, the evaluation set V = {I, II, III, IV, V} was determined and the corresponding water quality were divided into 5 grade, i.e. excellent (I), good (II), medium (III), poor (IV) and inferior (V). It reflects the degree of water pollution as clean, no pollution, light polluted, polluted and heavy polluted, respectively.

Membership degree calculation of evaluation index: By using the fuzzy membership formula (Hu, 2004), the membership degree (Table 3) related to the water

Table 1: The annual mean values of main physico-chemical factors measured at each sampling site in the Yongjiang River

Sampling site	Physico-chemical factors DO (mg/L)	BOD_5 (mg/L)	COD_{Mn} (mg/L)	TN (mg/L)	TP (mg/L)	AT (°C)	WT (°C)	Salty (‰)	TS (cm)
1	9.171	1.001	2.333	1.835	0.022	19.0	16.3	0.0	48.5
2	8.099	1.098	5.671	2.549	0.060	19.6	18.9	0.0	62.8
3	5.414	2.172	12.748	4.464	1.691	19.6	19.4	0.0	28.1
4	3.622	2.879	18.383	5.794	0.882	19.9	19.5	0.0	19.4
5	3.168	2.836	22.933	6.293	0.679	20.2	19.9	0.0	19.5
6	2.328	4.057	25.528	5.863	1.052	20.1	19.7	0.0	7.10
7	2.636	4.929	25.967	6.555	1.027	19.4	19.7	0.0	8.30
8	2.616	5.327	22.930	6.380	0.810	19.7	19.6	0.0	8.60
9	5.158	3.643	14.908	5.517	0.262	20.1	20.1	0.0	30.6
10	2.585	5.125	29.217	5.624	0.980	19.3	19.7	0.0	8.20
11	4.845	2.783	8.5380	3.587	0.630	19.5	19.7	8.8	5.60
12	5.218	1.944	8.2780	3.572	0.538	19.8	19.3	13.6	8.10
13	6.210	1.844	8.0990	3.014	0.505	18.9	19.0	13.8	9.30

AT: air temperature; WT: water temperature; TS: transparency

Table 2: Environmental quality standards - limit values (mg/L) of the surface water in different grades

Serial number	Factor		Water quality grade I	II	III	IV	V
1	DO	≥	7.5	6.000	5	3	2
2	COD_{Mn}	≤	15	15.00	20	30	40
3	BOD_5	≤	3	3.000	4	6	10
4	TP	≤	0.01	0.025	0.05	0.1	0.2
5	TN	≤	0.2	0.500	1.00	1.5	2.0

Table 3: The average degrees matrix R of membership for 5 indexes at 13 sampling sites in the Yongjiang River

		Index				
Sampling sites	Water quality grade	DO	COD_{Mn}	BOD_5	TP	TN
1	I	1	1	1	0.2	0
	II	0	0	0	0.8	0
	III	0	0	0	0	0
	IV	0	0	0	0	0.33
	V	0	0	0	0	0.67
2	I	1	1	1	0	0
	II	0	0	0	0	0
	III	0	0	0	0.8	0
	IV	0	0	0	0.2	0
	V	0	0	0	0	1
3	I	0	1	1	0	0
	II	0.414	0	0	0	0
	III	0.586	0	0	0	0
	IV	0	0	0	0	0
	V	0	0	0	1	1
4	I	0	0	1	0	0
	II	0	0.3234	0	0	0
	III	0.311	0.6766	0	0	0
	IV	0.689	0	0	0	0
	V	0	0	0	1	1
5	I	0	0	1	0	0
	II	0	0	0	0	0
	III	0.084	0.7067	0	0	0
	IV	0.916	0.2933	0	0	0
	V	0	0	0	1	1
6	I	0	0	0	0	0
	II	0	0	0	0	0
	III	0	0.4472	0.9715	0	0
	IV	0.328	0.5528	0.0285	0	0
	V	0.672	0	0	1	1
7	I	0	0	0	0	0
	II	0	0	0	0	0
	III	0	0.4033	0.5355	0	0
	IV	0.636	0.5967	0.4645	0	0
	V	0.364	0	0	1	1
8	I	0	0	0	0	0
	II	0	0	0	0	0
	III	0	0.707	0.3365	0	0
	IV	0.616	0.293	0.6635	0	0
	V	0.384	0	0	1	1
9	I	0	1	0	0	0
	II	0.158	0	0.357	0	0
	III	0.842	0	0.643	0	0
	IV	0	0	0	0	0
	V	0	0	0	1	1
10	I	0	0	0	0	0
	II	0	0	0	0	0
	III	0	0.0783	0.4375	0	0
	IV	0.585	0.9217	0.5625	0	0
	V	0.415	0	0	1	1
11	I	0	1	1	0	0
	II	0	0	0	0	0
	III	0.9225	0	0	0	0
	IV	0.0775	0	0	0	0
	V	0	0	0	1	1
12	I	0	1	1	0	0
	II	0.218	0	0	0	0
	III	0.782	0	0	0	0
	IV	0	0	0	0	0
	V	0	0	0	1	1
13	I	0.14	1	1	0	0
	II	0.86	0	0	0	0
	III	0	0	0	0	0
	IV	0	0	0	0	0
	V	0	0	0	1	1

Table 4: The normalized average weights *Ai* of 5 indexes from sampling sites in the Yongjiang River

	Index				
Sampling site	DO	COD_{Mn}	BOD_5	TP	TN
1	0.4547	0.0227	0.0449	0.0666	0.4112
2	0.3191	0.0438	0.0391	0.1443	0.4538
3	0.0406	0.0187	0.0147	0.7745	0.1514
4	0.0403	0.0401	0.0290	0.5992	0.2914
5	0.0395	0.0561	0.0320	0.5174	0.3550
6	0.0229	0.0492	0.0361	0.6314	0.2605
7	0.0252	0.0487	0.0426	0.6000	0.2835
8	0.0290	0.0498	0.0534	0.5482	0.3197
9	0.0986	0.0558	0.0630	0.3058	0.4768
10	0.0263	0.0583	0.0472	0.6093	0.2589
11	0.0761	0.0262	0.0395	0.6037	0.2545
12	0.0906	0.0282	0.0305	0.5703	0.2804
13	0.1152	0.0294	0.0309	0.5718	0.2527

quality grade was obtained and the membership degree matrix R was built.

Weight calculation of evaluation index: It could be found that the importance of water quality monitoring index (environment factors) may be the same, may be different during assessment on the water quality with fuzzy comprehensive method. So, it is necessary to consider the Weight (W) of evaluation index.

For the index with higher the value, the heavier the pollution, the weight index should be calculated as follow:

$$W_i = c_i / S_i$$

For the index with higher the value, the lighter the pollution, the weight index should be calculated as follow:

$$W_i = S_i / c_i$$

Here, ci is monitoring value of factor i, Si is the average limit value in standard of factor i.

It should be normalized with the formula for each individual weight as follow since the weight value calculated might be greater than 1:

$$A_i = W_i / \sum_{i=1}^{m} W_i$$

Here, Ai is the weight value of the normalized factor i, m is the number of monitoring index which used in the evaluation.

The normalized average weights Ai of 5 indexes from all sampling sites in the Yongjiang River were listed in Table 4.

Matrix B calculation of fuzzy comprehensive assessment: After establishing R and A, a fuzzy normal subset is obtained, which is the result of comprehensive assessment.

That is:

$$B = A \times R$$

$B = (b_1, b_2, b_3, \ldots b_n)$ is the comprehensive assessment result of fuzzy mathematics, which can be used to determine the grade of water quality based on the principle of the maximum membership degree after the comprehensive assessment is set.

In the comprehensive assessment with multi-index, especially when the environmental factor indexes belong to different water quality grades at the same sampling site, obtained results are not in conformity with the reality and it is possible to result in distortion, skip or homogenization.

In order to avoid the error and reflect the water quality grade truly, the weighted average principle was used in this study and the comprehensive assessment results were dealt with the formula as follow:

$$*B = \frac{\sum_{j=1}^{m} b_j^{k} \cdot j}{\sum_{j=1}^{m} b_j^{k}}$$

Here,b_j is the membership grade of grade j in water quality classification, k is the undetermined coefficient ($k = 1$ or $k = 2$).

*B value, weighted average evaluation level, not only can be used to evaluate the grade of water quality, but to sort the assessment results for several samples.

RESULTS AND DISCUSSION

After a series calculations mentioned above, the results of the water quality grade at all sampling sites in the Yongjiang River with the fuzzy comprehensive assessment were obtained and listed in Table 5. The principle of maximum membership degree should be adopted when to determine the final water quality grade at each sampling site. It means the final water quality grade should be determined by chosen the water quality grade closing to the secondary higher membership degree, when there were 2 or more than 2 of the same maximum degree of membership appeared at one site.

Table 5: Annual average results of water quality in the Yongjiang River with the fuzzy comprehensive assessment method

Sampling sites	Evaluation grades I	II	III	IV	V	*B	Water quality grade
1	0.5356	0.0533	0.0000	0.1357	0.2755	1.9419	II
2	0.4019	0.0000	0.1154	0.0289	0.4538	3.2349	IV
3	0.0335	0.0168	0.0238	0.0000	0.9259	4.9925	V
4	0.0290	0.0130	0.0396	0.0278	0.8907	4.9902	V
5	0.0320	0.0000	0.0429	0.0527	0.8724	4.9862	V
6	0.0000	0.0000	0.0570	0.0357	0.9073	4.9906	V
7	0.0000	0.0000	0.0425	0.0649	0.8926	4.9903	V
8	0.0000	0.0000	0.0532	0.0679	0.8790	4.9868	V
9	0.0558	0.0381	0.1235	0.0000	0.7826	4.9251	V
10	0.0000	0.0000	0.0252	0.0957	0.8791	4.9867	V
11	0.0657	0.0000	0.0702	0.0059	0.8582	4.9636	V
12	0.0587	0.0198	0.0709	0.0000	0.8507	4.9659	V
13	0.0765	0.0991	0.0000	0.0000	0.8245	4.9240	V

*B: value of weighted average evaluation level

Table 6: The seasonal results of water quality in the Yongjiang River with the fuzzy comprehensive assessment method

	Spring		Summer		Autumn		Winter	
Sampling sites	*B	Water quality grade	*B	Water quality grade	*B	Water quality grade	*B	Water quality grade
1	1.3068	II	3.5542	IV	3.3823	III	1.2302	II
2	2.5866	III	4.5341	V	4.2427	IV	1.5324	II
3	4.9942	V	4.9919	V	4.9930	V	4.9573	V
4	4.9858	V	4.9938	V	4.9933	V	4.9707	V
5	4.9911	V	4.9899	V	4.9883	V	4.9635	V
6	4.9929	V	4.9848	V	4.9978	V	4.9625	V
7	4.9972	V	4.9808	V	4.9932	V	4.9758	V
8	4.9908	V	4.9839	V	4.9924	V	4.9669	V
9	4.9632	V	4.9605	V	4.9302	V	4.3965	IV
10	4.9945	V	4.9972	V	4.9877	V	4.9752	V
11	4.9515	V	4.9926	V	4.9842	V	4.9311	V
12	4.9459	V	4.9884	V	4.9796	V	4.8533	V
13	4.8155	V	4.9570	V	4.9738	V	4.7050	V

*B: value of weighted average evaluation level

Table 7: The fuzzy comprehensive assessment results of water quality in the Yongjiang River

Items	Spring	Summer	Fall	Winter
*B	4.5012	4.8392	4.8030	4.3400
Water quality grade	V	V	V	IV

*B: value of weighted average evaluation level

According to the evaluation levels *B1~*B13={1.9419, 3.2349, 4.9925, 4.9902, 4.9862, 4.9906, 4.9903, 4.9868, 4.9251, 4.9867, 4.9636, 4.9659, 4.9240}, annual assessment results of water quality from all sampling sites in the Yongjiang River showed a trend as follows (from excellent to inferior): Sites 1, 2, 13, 9, 11, 12, 5, 10, 8, 4, 7, 6 and 3. The water quality reached Grade II and III at Site 1 and Site 2, respectively. Other sites were all in Grade V. The results were basically consistent with the reports from WeiHong*et al*. (2013) using the water chemical index and similar to Xianying *et al*. (2013) analysing phytoplankton community structure, Teng*et al*. (2014) with biological integrity index (BI)) and Zhang *et al*. (2013) by the planktonic rotifer tolerance value in the Yongjiang River.

The assessment results of water quality grade in different seasons at each sampling site in the Yongjiang River were list in Table 6 as well.

Table 6 showed that there were some differences in water quality among the different seasons even at the same sampling site, especially in upstream, but the Yongjiang River was polluted overall.

If considered the Yonhjiang River as a whole, the water quality in different seasons was displayed in Table 7.

It showed that the water quality of the Yongjiang River in different seasons, from excellent to inferior, was as follows: winter, spring, autumn and summer. It was Grade IV in winter and Grade V in other seasons.

CONCLUSION

Fuzzy mathematics comprehensive analysis shows that the water quality of the Yongjiang River at the upstream sections was better than that at the downstream sections. The water qualities of the different sections from superior to inferior of the entire order are: Section 1> Section 2> Section 13> Section 9> Section 11> Section 12> Section 5> Section 10> Section 8> Section 4> Section 7> Section 6> Section 3. Except for section 1, 2 and 9, water quality at all sections appeared Level V. And in the different seasons, it presents winter> spring> summer> autumn. It is found that the water quality at all sampling sections in the Yongjiang River was poor in Grade IV in winter and Grade V in other seasons.

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