Comparative Analysis and Comprehensive Evaluation of Fishery Water Quality of the Major Lakes in Jiangsu Province Based on Long-term Monitoring Data

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Abstract The variance analysis of fishery water quality data of five lakes from 2001 to 2011 (except 2004) was performed to compare the difference of the monitoring indicators among the five above-mentioned lakes in Jiangsu Province. And TOPSIS method was employed to give comprehensive comparison of water quality of the five lakes. The results indicated that the difference of 14 major water quality indicators was very significant among lakes except copper. In addition, transparency, total nitrogen, total phosphorus had very significant difference among stations for each lake; pH, chemical oxygen demand, oil, total phosphorus, lead, cadmium, mercury had significant or very significant difference among years for each station. The TOPSIS results showed that the fishery water quality of Gaobaoshaobo Lake was the best, and Luoma Lake was just second to it, followed by Hongze Lake, Taihu Lake and Gehu Lake. In combination with the geographic position of each lake, it showed that fishery water quality of the five investigated lakes was basically increasingly better from the south to the north in Jiangsu Province, and the trend revealed high association with the developed industrial economy.

Key words Lake, Fishery water quality, Comprehensive comparison

1 Introduction

For decades, with China's population growth and development of industrial and agricultural production, coupled with over-exploitation of the lake water, some problems have become increasingly prominent such as lake water shortage, deterioration of water environment and ecosystem degradation, posing a serious threat to sustainable socio-economic development and human health[1]. Jiangsu is one of provinces with many freshwater lakes in China, including Taihu Lake, Gehu Lake, Hongze Lake, Gaobaoshaobo Lake and Luoma Lake. The study based on Taihu Lake and Hongze Lake is hot at home[2-8]. Over the years, the authorities have carried out the fishery environmental monitoring on the protected areas, enclosure culture areas and other functional areas of these five lakes, but it still lacks systematic analysis of huge fishery water quality monitoring data on these lakes. The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) is a multi-criteria decision analysis method, which was originally developed by Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993. TOPSIS is based on the concept that the chosen alternative should have the shortest geometric distance from the positive ideal solution and the longest geometric distance from the negative ideal solution. It is a method of compensatory aggregation that compares a set of alternatives by identifying weights for each criterion, normalising scores for each criterion and calculating the geometric distance between each alternative and the ideal alternative, which is the best score in each criterion. An assumption of TOPSIS is that the criteria are monotonically increasing or decreasing. Normalisation is usually required as the parameters or criteria are often of incongruous dimensions in multi-criteria problems. Compensatory methods such as TOPSIS allow trade-offs between criteria, where a poor result in one criterion can be negated by a good result in another criterion. This provides a more realistic form of modelling than non-compensatory methods, which include or exclude alternative solutions based on hard cut-offs. TOPSIS applies to small-sample data, and also multi-sample large-scale systems, so it has been widely used in the field of health care, economy and agriculture[9-10]. Using variance analysis of system packet data, we perform the statistical analysis of fishery water quality data on five lakes which are long monitored in Jiangsu Province, to identify the significance of differences between lakes, stations or years. On this basis, using TOPSIS, we conduct a comparative analysis of fishery water quality of five lakes and summarize their variation, which can help to further explore the relationship between fishery water quality differences and economic development around lake basin and can also provide technical support for the development of regional industry policy.

2 Materials and methods

2.1 Data sources The fishery water quality monitoring data

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about Taihu Lake, Gehu Lake, Hongze Lake, Gaobaoshaobo Lake and Luoma Lake during 2001 – 2011 (excluding 2004) are provided by Jiangsu Provincial Fishery Ecological Environment Monitoring Station. It was monitored 413 times in Taihu Lake, 183 times in Gehu Lake, 205 times in Hongze Lake, 221 times in Gaobaoshaobo Lake and 142 times in Luoma Lake. The total data capacity is 13537.

2.2 Monitoring indicators and determination methods The instantaneous sampling method is to collect the surface water samples, and 15 monitoring indicators include water temperature, transparency, pH, dissolved oxygen, chemical oxygen demand, permanganate index, petroleum, ammonia nitrogen, total nitrogen, total phosphorus, copper, lead, cadmium, mercury and arsenic. Water temperature, transparency, pH and dissolved oxygen are determined on-site and other water samples are fixed with reagent to be brought back to laboratory for analysis. *Water and Wastewater Monitoring and Analysis Method*[11] is used for sample fixation and analysis; the evaluation standard is based on GB11607 – 89 *Fishery Water Quality Standard* and GB3838 – 2002 *Surface Water Quality Standards*.

2.3 Statistical analysis methods

2.3.1 Variance analysis of grouping data. With lake as group, monitoring station within lake as subgroup and year as small subgroup, we perform the variance analysis of three-level grouping data, to compare the significance differences between monitoring indicators

2.3.2 Comprehensive evaluation of water quality using TOPSIS method. (i) Establishing the original data matrix with the same trend in order to eliminate the effect of differences in indicators, dimensions and order of magnitude on the evaluation results. (ii) Normalizing the original data matrix of the same trends and establishing normalized data matrix, formula: $u = (x - x_{min})(x_{max} - x_{min})^{-1}$. (iii) Getting the optimal value vector A^+ and worst value vector A^- according to the normalized matrix. (iv) Calculating the distance between evaluation indicator values and the optimal solution (D_i^+) or worst solution (D_i^-), formula: $D_i^+ = \sqrt{\Sigma(a_{ij\max} - a_{ij})^2}$ and $D_i^- = \sqrt{\Sigma(a_{ij\min} - a_{ij})^2}$. (v) Calculating the closeness between evaluation indicators and the optimal solution, formula: $C_i = D^- / (D^- + D^+)$, the smaller the value of C_i, the better the water quality.

3 Results and analysis

3.1 Physical and chemical characteristics of water quality of five lakes The size of the water transparency not only affects the phytoplankton photosynthesis, but also broadly reflects phytoplankton abundance and fertility of water quality. The water with pH values below 6.5 can reduce pH values of blood in aquaculture animals and impair oxygen-carrying capacity of the blood, resulting in physiological hypoxia of aquaculture animals; the water with too high pH values can corrode fish gill and affect its respiratory function. Dissolved oxygen is an important indicator of water pollution. When the dissolved oxygen disappears, the anaerobic bacteria reproduce to release methane, hydrogen sulfide, ammonia and other toxic gases. Chemical oxygen demand is the consumption amount with potassium dichromate as the oxidant, and permanganate index is the consumption amount with potassium permanganate as the oxidant. Both of them are composite indicators that reflect the pollution of organic pollutants and reducing inorganic matter to the surface water. Petroleum has strong toxicity to fish and other aquatic organisms, and can be stored in fat to be accumulated in organisms. The ammonia nitrogen in water is a form of nitrogen with the greatest hazards, and a major oxygen-consuming pollutant in water. Total nitrogen is an important indicator to measure water quality, and increasing total nitrogen and excessive phosphorus will make phytoplankton flourish and lead to water eutrophication, thereby damaging the oxygen balance in water. At the same time, the dead algae and other types of phytoplankton will release toxins, causing further contamination of the water. Table 1 shows that the water temperatures of five lakes range from 20.32 to 23.10℃, and the coefficient of variation is between 0.19 and 0.34. For the five lakes, Luoma Lake has the highest transparency (0.86 m), followed by Gaobaoshaobo Lake (0.62 m), and Gehu Lake has the lowest transparency (0.36 m). The pH values of five lakes changed little, and the coefficient of variation is between 0.06 and 0.08. The dissolved oxygen of five lakes ranges from 7.86 to 9.26 mg · L^{-1}, and the coefficient of variation is between 0.24 and 0.30. In Gehu Lake, the chemical oxygen demand and permanganate index are high (36.43 mg · L^{-1} and 6.46 mg · L^{-1}, respectively), and the coefficient of variation is 0.28 and 0.27, respectively. The coefficient of variation of permanganate index (0.97) is large in Gaobaoshaobo Lake. The petroleum content is highest in Hongze Lake (76.40 μg · L^{-1}), and the coefficient of variation is largest (0.98). The ammonia nitrogen content is highest in Taihu Lake (0.55 mg · L^{-1}), and the coefficient of variation is largest (0.91). The total nitrogen and total phosphorus are largest in Gehu Lake (3.18 and 0.18 mg · L^{-1}, respectively), and the coefficient of variation is 0.51 and 0.88, respectively. Copper, lead, cadmium, mercury and arsenic are in line with *Fishery Water Quality Standards*, but the relative variation is large.

3.2 Differences in water quality indicators for five lakes Table 2 shows that except copper, there are highly significant differences in 14 water quality indicators among the five lakes, which may be caused by different utilization modes of these lakes. There are significant differences in transparency, total nitrogen and total phosphorus between the stations in lakes, while there are no significant differences in other indicators. There are significant or highly significant differences in pH values, chemical oxygen demand, petroleum, total phosphorus, lead, cadmium and mercury content between years, indicating that there is interannual instability in these indicators.

Table 1 Basic statistics of fishery water quality indicators for the five lakes from 2001 to 2011

Lakes	Statistics	Water temperature ℃	Transparency m	pH	Dissolved oxygen mg·L⁻¹	Chemical oxygen demand mg·L⁻¹	Permanganate index mg·L⁻¹	Petroleum μg·L⁻¹	Ammonia nitrogen μg·L⁻¹	Total nitrogen μg·L⁻¹	Total phosphorus μg·L⁻¹	Copper μg·L⁻¹	Lead μg·L⁻¹	Cadmium μg·L⁻¹	Mercury μg·L⁻¹	Arsenic μg·L⁻¹
Taihu Lake	Mean	22.52	0.42	7.95	8.18	31.56	4.15	46.20	0.55	2.13	0.11	5.72	3.84	1.03	0.08	10.40
	Standard deviation	6.31	0.31	0.56	1.96	11.99	1.49	42.50	0.50	1.62	0.11	5.49	3.15	0.75	0.07	9.67
	The coefficient of variation	0.28	0.73	0.07	0.24	0.38	0.36	0.92	0.91	0.76	0.98	0.96	0.82	0.73	0.91	0.93
Gehu Lake	Mean	22.99	0.36	8.10	9.26	36.43	6.46	48.90	0.43	3.18	0.18	5.89	3.46	0.75	0.15	2.61
	Standard deviation	4.83	0.26	0.49	2.69	10.20	1.74	42.05	0.37	1.62	0.16	5.12	3.01	0.67	0.14	1.75
	The coefficient of variation	0.21	0.71	0.06	0.29	0.28	0.27	0.86	0.87	0.51	0.88	0.87	0.87	0.89	0.96	0.67
Hongze Lake	Mean	21.52	0.40	8.40	7.86	23.51	4.31	76.40	0.34	1.39	0.11	4.99	3.70	1.44	0.17	1.77
	Standard deviation	5.81	0.27	0.59	2.28	5.64	1.51	74.87	0.19	1.13	0.11	4.84	3.40	1.38	0.15	1.04
	The coefficient of variation	0.27	0.68	0.07	0.29	0.24	0.35	0.98	0.56	0.81	0.99	0.97	0.92	0.96	0.87	0.59
Gaobaoshaobo Lake	Mean	23.10	0.62	8.01	8.49	21.13	7.72	15.90	0.25	1.61	0.08	4.26	3.27	1.19	0.07	1.68
	Standard deviation	4.39	0.48	0.64	2.55	12.89	7.49	12.88	0.18	1.19	0.08	3.79	3.04	1.09	0.02	0.76
	The coefficient of variation	0.19	0.78	0.08	0.30	0.61	0.97	0.81	0.70	0.74	0.95	0.89	0.93	0.92	0.34	0.45
Luoma Lake	Mean	20.32	0.86	8.43	8.37	22.02	3.56	43.70	0.23	1.60	0.05	3.73	8.54	0.23	0.19	1.15
	Standard deviation	6.91	0.58	0.67	2.01	3.74	1.00	33.65	0.17	1.15	0.05	3.21	8.20	0.20	0.16	0.66
	The coefficient of variation	0.34	0.68	0.08	0.24	0.17	0.28	0.77	0.74	0.72	0.95	0.86	0.96	0.80	0.86	0.57

Table 2 Variance analysis results of main water quality indicators for the five lakes

Sources of variation	Water temperature			Transparency			pH			Dissolved oxygen			Chemical oxygen demand		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Between lakes	4	156.08	24.9**	4	4.76	14.36**	4	11.07	22.66**	4	38.72	6.65**	4	6058.52	36.53**
Between stations	117	6.27	0.40	114	0.33	1.94**	115	0.49	1.06	116	5.82	1.28	100	165.86	0.87
Between years	224	15.77	0.30	147	0.17	2.01**	302	0.46	1.95**	306	4.56	0.87	166	190.71	2.47**
Error	414	52.61		307	0.08		394	0.24		524	5.27		477	77.33	
Total	759			572			815			950			747		

Sources of variation	Permanganate index			Petroleum			Ammonia nitrogen			Total nitrogen			Total phosphorus		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Sources of variation	df	MS	F	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Between lakes	4	291.23	4.12**	4	0.09	6.21**	4	3.01	23.88**	4	97.63	22.38**	4	0.41	10.71**
Between stations	113	70.65	19.53**	122	0.02	1	114	0.13	1.09	119	4.36	2.55**	119	0.04	2**
Between years	169	3.62	0.14	356	0.02	2*	251	0.12	0.90	367	1.71	1.09	366	0.02	2**
Error	369	25.86		634	0.01		382	0.13		639	1.57		626	0.01	
Total	655			1116			751			1129			1115		

Sources of variation	Permanganate index			Lead			Cadmium			Mercury			Arsenic		
	df	MS	F	df	MS	F	df	MS	F	df	MS	F	df	MS	F
Between lakes	4	1.56E-04	0.66	4	6.23E-04	33.97**	4	3.29E-05	8.92**	4	4.89E-07	19.92**	4	3.70E-03	5.25**
Between stations	113	2.38E-04	0.96	110	1.84E-05	0.32	108	3.69E-06	0.41	114	2.46E-08	0.77	113	7.04E-04	0.56
Between years	351	2.47E-04	1.08	340	5.79E-05	5.68**	328	8.94E-06	1.19*	328	3E-08	1.50**	328	1.26E-03	1.14
Error	596	2.29E-04	550	1.02E-05	503	7.48E-06	539	2E-08	471	1.10E-03					
Total	1064			1004				943			985			916	

Table 3 shows that Gaobaoshaobo Lake has the highest water temperature, significantly different from Luoma Lake but not significantly different from Gehu Lake, Taihu Lake and Hongze Lake; Luoma Lake has the highest transparency, followed by Gaobaoshaobo Lake, and there are not significant differences in transparency among Gehu Lake, Taihu Lake and Hongze Lake. The dissolved oxygen of five lakes is in line with *Fishery Water Quality Standards*, and it is highest in Gehu Lake, significantly different from other lakes. The chemical oxygen demand concentration of Gehu Lake and Taihu Lake is 36.43 mg · L^{-1} and 31.56 mg · L^{-1}, respectively, and the water quality reaches Grade Ⅴ of *Surface Water Environment Quality Standards*; there is significant difference between the two, and the water quality of the other three lakes reaches Grade Ⅳ. In terms of permanganate index, Gaobaoshaobo Lake and Gehu Lake reach Grade Ⅳ of *Surface Water Environment Quality Standards*, and there is no significant difference between the two; Taihu Lake and Hongze Lake reach Grade Ⅲ; Luoma Lake reaches Grade Ⅱ, not significantly different from Taihu Lake and Hongze Lake. Only the petroleum indicator in water quality of Hongze Lake does not reach *Fishery Water Quality Standards*, significantly different from the other four lakes, and the petroleum content is lowest in Gaobaoshaobo Lake (15.90 μg · L^{-1}). The ammoniacal nitrogen is highest in Taihu Lake (0.55 mg · L^{-1}), reaching Grade Ⅲ of *Surface Water Environment Quality Standards*, significantly different from the other four lakes which reach Grade II. The total nitrogen of Gehu Lake and Taihu Lake is 3.18 mg · L^{-1} and 2.13 mg · L^{-1}, respectively, reaching Grade V of Surface Water *Environment Quality Standards*, and there is a significant difference between the two. The total phosphorus content of five lakes does not exceed Grade V of *Surface Water Environment Quality Standards*. The total phosphorus content is highest in Gehu Lake (0.18 mg · L^{-1}), significantly different from other lakes, and the total phosphorus content is lowest in Luoma Lake (0.05mg · L^{-1}), reaching Grade Ⅲ of *Surface Water Environment Quality Standards*. The lead, cadmium, mercury and arsenic content of five lakes are in line with *Fishery Water Quality Standards*. The lead concentration is highest in Luoma Lake (8.54μg · L^{-1}), significantly different from the other four lakes. The cadmium content is highest in Hongze Lake (1.44 μg · L^{-1}), not significantly different from Taihu Lake and Gaobaoshaobo Lake but significantly different from Gehu Lake and Luoma Lake. The mercury content is highest in Luoma Lake (0.19 μg · L^{-1}), not significantly different from Hongze Lake but significantly different from the other three lakes. The arsenic content is highest in Taihu Lake (10.40 μg · L^{-1}), significantly different from the other four lakes.

Table 3 The multiple comparisons of main water quality indicators for the five Lakes

Lakes	Water temperature ℃	Transparency m	pH	Dissolved oxygen mg · L^{-1}	Chemical oxygen demand mg · L^{-1}	Permanganate index mg · L^{-1}	Petroleum μg · L^{-1}
Taihu Lake	22.52a	0.42c	7.95d	8.18bc	31.56b	4.15b	46.20b
Gehu Lake	22.99a	0.36c	8.10c	9.26a	36.43a	6.46a	48.90b
Hongze Lake	21.52ab	0.40c	8.40b	7.86c	23.51c	4.31b	76.40a
Gaobaoshaobo Lake	23.10a	0.62b	8.01cd	8.49b	21.13d	7.72a	15.90c
Luoma Lake	20.32b	0.86a	8.43a	8.37bc	22.02cd	3.56b	43.70b

Lakes	Ammonia nitrogen mg · L^{-1}	Total nitrogen mg · L^{-1}	Total phosphorus mg · L^{-1}	Lead μg · L^{-1}	Cadmium μg · L^{-1}	Mercury μg · L^{-1}	Arsenic μg · L^{-1}
Taihu Lake	0.55a	2.13b	0.11b	3.84b	1.03ab	0.08c	10.40a
Gehu Lake	0.43b	3.18a	0.18a	3.46b	0.75bc	0.15b	2.61b
Hongze Lake	0.34c	1.39c	0.11b	3.70b	1.44a	0.17ab	1.77b
Gaobaoshaobo Lake	0.25d	1.61c	0.08c	3.27b	1.19ab	0.07c	1.68b
Luoma Lake	0.23d	1.60c	0.05d	8.54a	0.23c	0.19a	1.15b

Note: Values in each column followed by different letters are significantly different at the 0.05 level.

Table 4 Normalization results of main water quality indicators concerning five lakes

Lakes	Transparency	Dissolved oxygen	Chemical oxygen demand	Perman – ganate index	Petroleum	Ammonia nitrogen	Total nitrogen	Total phosphorus	Copper	Lead	Cadmium	Mercury	Arsenic
Taihu Lake	0.754	0.741	0.681	0.141	0.500	1.000	0.413	0.461	0.909	0.060	0.666	0.077	1.000
Gehu Lake	1.000	0.000	1.000	0.697	0.544	0.625	1.000	1.000	1.000	0.000	0.500	0.641	0.161
Hongze Lake	0.828	1.000	0.155	0.180	1.000	0.343	0.000	0.461	0.590	0.060	1.000	0.816	0.075
Gaobaoshaobo Lake	0.278	0.509	0.000	1.000	0.000	0.062	0.122	0.230	0.272	0.020	0.916	0.000	0.064
Luoma Lake	0.000	0.597	0.058	0.000	0.458	0.000	0.117	0.000	0.000	1.000	0.000	1.000	0.000

3.3 Comprehensive water quality evaluation of five lakes

Water temperature and pH do not have the same trend, so we select 13 indicators such as transparency, dissolved oxygen and chemical oxygen demand for TOPSIS analysis. Transparency and dissolved oxygen are high quality indicators and other indicators are low quality indicators, therefore, we take the reciprocal of transparency and dissolved oxygen to convert them into low quality indicators. We normalize the data with the same trend and establish the corresponding normalized data matrix (Table 4). The optimum value vector A^{+} and the worst value vector A^{-} are as follows: $A^+ = \min(0,0,0,0,0,0,0,0,0,0,0,0,0)$ 和 $A^- = \max(1,1,1,1,1,1,1,1,1,1,1,1,1)$. Table 5 shows that C_i value of Gaobaoshaobo Lake is smallest (0.345) and C_i value of Gehu Lake is largest (0.582), the fishery water quality is best in Gaobaoshaobo Lake and worst in Gehu Lake. C_i value of Luoma Lake is 0.347, almost the same as C_i value of Gaobaoshaobo Lake, indicating that the comprehensive water quality of Luoma Lake is almost the same as that of Gaobaoshaobo Lake. Gaobaoshaobo Lake has the best fishery water quality, followed by Luoma Lake, Hongze Lake, Taihu Lake and Gehu Lake, and the water quality is getting better from south to north.

Table 5 Water quality evaluation results of five lakes

Lakes	D_i^+	D_i^-	C_i	Order
Taihu Lake	1.924	2.349	0.549	4
Gehu Lake	1.876	2.619	0.582	5
Hongze Lake	2.252	2.257	0.500	3
Gaobaoshaobo Lake	2.893	1.525	0.345	1
Luoma Lake	3.020	1.607	0.347	2

4 Conclusions and discussions

This paper performs the variance analysis on fishery water quality monitoring data of five lakes in Jiangsu Province during 2001 – 2011 (excluding 2004), compares differences in monitoring indicators between lakes, and uses TOPSIS method to carry out comprehensive evaluation of water quality of five lakes. The results show that except copper, there are highly significant differences in 14 indicators between five lakes; there are highly significant differences in transparency, total nitrogen and total phosphorus between stations; there are significant or highly significant differences in pH, chemical oxygen demand, petroleum, total phosphorus, lead, cadmium and mercury between years; fishery water quality is best in Gaobaoshaobo Lake, and Luoma Lake has similar water quality, followed by Hongze Lake, Taihu Lake and Gehu Lake, and the water quality is getting better from south to north. With population growth and rapid economic development in the surrounding areas of five lakes in Jiangsu Province, the total nitrogen, total phosphorus, heavy metals and other pollutants increase in the lake, and lake water pollution has been increasing[12]. Due to different utilization patterns of various lakes, there are differences in fishery water quality of five lakes in Jiangsu Province. How to control the effects of different utilization ways on water is to be further explored. There are many methods to assess water environment, such as fuzzy clustering analysis, comprehensive index method, gray system analysis and factor analysis[13-16], and these methods have advantages and disadvantages. TOPSIS method is used to normalize indicators and eliminate the effects of different dimensions, and it can quantitatively reflect the quality of different evaluation units. It is a good flexible comprehensive evaluation method without special requirements of sample data[17]. Previous fishery water quality monitoring data only used simple bar chart to describe whether the monitoring indicators exceed standard. In this study, we use variance analysis for the first time to process the fishery water quality monitoring data that have been long monitored, and adopt TOPSIS method to study the differences between 13 fishery water quality indicators in five lakes. This method is an ideal method to comprehensively evaluate water quality.

References

[1] PU PM, WANG GX, LI ZK, *et al*. Degradation of healthy aqua-ecosystem and its remediation: Theory, technology and application[J]. Journal of Lake Science, 2001, 13 (3): 193 – 203. (in Chinese).

[2] CHENG F, LING QF, XU HJ, *et al*. Assessment of water quality of Taihu and the main pollutions Lake[J]. Journal of Shanghai Fisheries University, 2010, 19 (1): 105 – 110. (in Chinese).

[3] LI B, PU PM, HAN AM. Spatio-temporal correlation analysis of water quality in Hongze Lake[J]. Journal of Lake Science, 2002, 14(3): 259 – 266. (in Chinese).

[4] GAO YN, GAO JF, CHEN SF, *et al*. Delineation of level III aquatic ecological function regionalization in the Taihu Lake basin[J]. Geographical Research, 2012, 31(11): 1941 – 1951. (in Chinese).

[5] YUAN HZ, SHEN J, LIU EF. Assessment and characterization of heavy metals and nutrients in sediments from Taihu Lake[J]. Chinese Journal of Environmental Science, 2011, 32(3): 649 –657. (in Chinese).

[6] LIU RM, WANG XJ, ZHENG Y, *et al*. Medium small scale spatial structures of water quality parameters in Lake Tai[J]. Resources and Environment in the Yangtza Basin, 2002, 11(1):32 –35. (in Chinese).

[7] ZHANG SW, LIU MS, XU C, *et al*. The dynamics and spatial correlation of water quality of seven rivers of Hongze Lake in Sihong county[J]. Journal of Nanjing Forestry University(Natural Sciences), 2012, 36(4): 36 –40. (in Chinese).

[8] LI B, PU PM. Study on the evolution tendency of water quality in Huai River Basin and Hongze Lake[J]. Resources and Environment in the Yangtza Basin, 2003, 12(1): 67 –73. (in Chinese).

[9] LIU YX, XU SQ. Multi-index comprehensive evaluation on the application of TOPSIS method in the quality of hospital work[J]. Chinese Journal of Health Statistics, 1993, 10(2): 12 – 15. (in Chinese).

[10] LEI ZB, ZHU ZW, WANG L. Diagnosis model for enterprse economic performance based on the weighing entropy inclination-TOPSIS[J]. Operations Research and Management Science 2005, 14(2): 142 – 148. (in Chinese).

[11] Ministry of Environmental Protection of the People's Republic of China. Determination methods for examination of water and wastewater[M]. Beijing: China Environmental Science Press. (in Chinese).

[12] YANG GS, MA RH, ZHANG L, *et al*. Lake status, major problems and protection strategy in China[J]. Journal of Lake Science, 2010, 22(6): 799 –810. (in Chinese).

[13] GUO GW, WANG MX, YU YS, *et al*. Fuzzy cluster analysis of water environmental unit in Qiannan area[J]. Modern Preventive Medicine, 2008, 35(24): 4766 – 4768. (in Chinese).

[14] PENG XJ, ZHANG YH, LI HH. Application of fuzzy comprehensive evaluation in groundwater quality assessment[J]. Water Sciences and Engineering Technology, 2008(6): 46 –48. (in Chinese).

[15] ZHENG JQ. The assessment of water environmental quality on grey decision-making[J]. Science-Technology and Management, 2003, 5(3): 29 – 31. (in Chinese).

[16] YANG W, LU WX, LI P, *et al*. Application of factor analysis method to the water quality evaluation of Yitong River[J]. Research of Soil and Water Conservation, 2007, 14(1): 113 –114. (in Chinese).

[17] ZHANG RM, ZHANG TY, HAN ZJ, *et al*. The application of TOPSIS method in the evaluation of surface water quality[J]. Water Resources & Hydropower of Northeast China, 2006, 24(7): 51 – 53. (in Chinese).