Water pollution assessment and health risk analysis of Puzhehei Lake

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Abstract. Puzhehei Lake is located in Wenshan Prefecture, Yunnan Province. Water pollution assessment is of great significance for the pollution control of the lake and the sustainable development of the basin. This study evaluates the water pollution and eutrophication status of three sampling points (upstream, middle and downstream) of Puzhehei Lake based on single factor evaluation method, comprehensive pollution index method and improved comprehensive pollution index method based on entropy weight method, and analyzes the water health risk. The results show that the water quality of the three sampling points is sub-class V using the single factor evaluation method. The water quality evaluation result based on the traditional comprehensive pollution index method shows that the water quality of the three sampling points belongs to heavy pollution. By contrast, the improved comprehensive pollution index method based on entropy weight method shows that the water quality of Leshui Cave belongs to class V, while the water quality of Puzhehei Village and Karst Wetland Park belongs to class V. According to the comprehensive evaluation method, the water quality of the three sampling points before and after correction is ranked from good to bad as follows: Leshui Cave, Karst Wetland Park and Puzhehei Village. The water bodies of Leshui Cave and Puzhehei Village are moderately nutritious, and the water bodies of Karst Wetland Park are oligotrophic. The chemical carcinogens health risk in water at the three sampling points exceeded the standard seriously, and the risk ranking was as follows: Karst Wetland Park > Leshui Cave > Puzhehei Village, in which Cr exceeded the standard seriously. The non carcinogenic health risk are low, and the risk ranking is Puzhehei Village > Leshui Cave > Karst Wetland Park. In the future water quality control, we should focus on the strict control of TN and TP in rivers entering the lake.

Key words: Puzhehei Lake; Entropy weight method; Comprehensive pollution index; Eutrophication; Water health risk.

1. Introduction

The lake ecosystem plays a variety of ecological service functions such as providing drinking water resources, flood control and irrigation, and climate regulation[1]. In recent years, the unreasonable development and utilization of lake resources by humans has caused many problems such as lake area shrinkage, water pollution, and biodiversity loss[2-3]. Since the quality of lake water quality is closely related to the health and safety of regional drinking water, the National Academy of Sciences (NAS) and the United States Environmental Protection Agency (USEPA) took the lead in introducing a health risk assessment model in the 1980s, which provided quantitative information on the relationship between environmental pollution and human health[4-6].
Puzhehei Lake is the largest karst lake in southeastern Yunnan. Its unique topography and lake ecosystem have important research value, and it is also a source of local drinking water[7]. In recent years, the fragility of the karst structure and unreasonable human activities have led to the pollution and destruction of the water quality of Puzhehei Lake, and its water environment protection is facing severe challenges[8].
On the basis of relevant domestic and foreign research, we used the improved comprehensive index based on entropy weight method to evaluate the water pollution status of the upper, middle and lower reaches of Puzhehei Lake, used the health risk assessment model to evaluate the lake. The aim of the present study is provide a theoretical basis for water pollution control and water environment health protection in the study area.

2. Methods

2.1 Sampling

Three sampling points were set to the upper, middle and lower reaches of Puzhehei Lake, namely Leshui Cave, Puzhehei Village and Karst Wetland Park, sampling on

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December 6, 2020. The water was sampled with a 500ml capacity sampling bottle, and two sets of replicates were set for each sampling point. During sampling, choose to take samples at a depth of 0.1~0.2m in the lake when the water level is stable, and avoid shaking the water body. After sampling, tighten the bottle cap to avoid oxidation reaction, and store it in an incubator at about 4℃ away from light, and then send it to the testing station for analysis on December 8, 2020. A total of 11 water quality indicators including COD, TN, NH3-N, TP, Cu, Zn, Pb, Cd, Cr, As and Hg were selected for testing.

2.2 Comprehensive index based on entropy weight method

The traditional comprehensive pollution index ignores the weight of each pollution index in the evaluation system. We used the entropy weight method to optimize the comprehensive pollution index, and eliminated the interference of other factors as much as possible[9-10]. The larger the entropy weight, the greater the influence of the index on the evaluation results.

The steps for calculating the weight of each indicator are to first normalize each index value (xij) detected by the three sampling points, then calculate the entropy value Ei of the index (k=lnm), and finally calculate the information weight coefficient ωi (Formula 1-4).

$$p(x_{ij}) = \frac{x_{ij}}{\sum_{j=1}^{n} x_{ij}} (i = 1,2,\ldots,m;\ j = 1,2,\ldots,\mathrm{n}) \quad (1)$$

$$E_i = -k\sum_{j=1}^{n} p(x_{ij}) \ln p(x_{ij}) \quad (2)$$

$$d_i = 1 - E_i \quad (3)$$

$$\omega_i = \frac{d_i}{\sum_{i=1}^{m} d_i} (i = 1,2,\ldots,\mathrm{m}) \quad (4)$$

In the formula, p(xij) is the normalized standard value of each index, Ei is the information entropy, and ωi is the weight value of the pollution index i.

Therefore, the improved comprehensive index based on entropy weight method has the following formula:

$$P' = \sum_{i=1}^{m} \omega_i P_i \quad (5)$$

2.3 Health risk assessment model

At present, the health risk analysis of water environment often adopts the health risk assessment model recommended by USEPA, which is divided into chemical carcinogen and non-carcinogen health risk assessment models according to the type of chemicals. The specific formula is referenced from [11].

3. Results

3.1 Water quality evaluation

The weights of Zn, Pb, and Cd were the highest, all greater than 0.10, the weights of other indicators ranged from 0.06 to 0.09, and the weights of Cu and As were the lowest. The comprehensive index evaluation results showed that the index of Puzhehei Village is the highest, followed by Karst Wetland Park, and Leshui Cave is the lowest. It can be seen that the water quality in the upper reaches was relatively the best, the lower reaches was the second, and the middle reaches was the worst. The results of water quality grade evaluation showed that Leshui Cave (upstream) belongs to Class V water, while Puzhehei Village and Karst Wetland Park (middle and downstream) was inferior to Class V (Table 1-3).

Table 1. Weight of each pollution index of Puzhehei Lake

Index	COD	TN	NH_3-N	TP	Cu	Zn	Pb	Cd	Cr	As	Hg
ω_i	0.0698	0.0808	0.0797	0.0717	0.0676	0.1348	0.1408	0.1292	0.0724	0.0676	0.0856

Table 2. Evaluation standard of comprehensive index method based on entropy method

Water quality grade	I	II	III	IV	V
Value	0.27	0.71	1.00	2.12	2.62

Table 3. Evaluation results of traditional and modified comprehensive pollution index method

Sampling point		P'	Average value	Water quality grade
Leshui Cave (the upper reach)	Sampling 1	3.03	2.49	Grade V
	Sampling 2	1.95		
Puzhehei Village (the middle reach)	Sampling 1	5.13	4.84	Inferior Grade V
	Sampling 2	4.54		
Puzhehei National Wetland Park (the lower reach)	Sampling 1	3.34	2.67	Inferior Grade V
	Sampling 2	2.00		

3.2 Water health risk assessment

The overall health risks of chemical carcinogens in the water bodies of the three sampling points in Puzhehei Lake exceeded the maximum risk level (5.0×10-5·a-1) accepted by the International Commission on Radiation Protection, and the order was: Karst Wetland Park > Leshui Cave > Puzhehei Village. The health risks of Cd and As chemical carcinogens were lower than the maximum risk level accepted by the International Commission on Radiation Protection, but slightly higher than the risk level acceptable to USEPA.

The health risks of non-carcinogens at the three sampling points were all lower than the negligible risk level (1×10-8 ·a-1) recommended by the Netherlands Construction and Environment Agency and the negligible risk level (1×10-7·a-1) recommended by the Royal Society of England. The order was: Puzhehei Village > Leshui Cave > Karst Wetland Park. The health risks of each indicator of non-carcinogens from high to low were: Hg, NH3-N, Pb, Cu, Zn.

In general, the total health risk ranking of the three sampling points in Puzhehei Lake was as follows: Karst Wetland Park > Leshui Cave > Puzhehhe Village, and the total health risk values were very high. The health risk of chemical carcinogens occupied an absolute proportion in the total health risk, and the risk contribution rate was very high. Among them, the health risk of Cr was the highest, which played a decisive role in the overall health risk of the lake. In the future health protection of drinking water in Puzhehei Lake, the discharge of Cr into the lake should be strictly controlled, and the treatment of such chemical pollutants should be strengthened to ensure the safety of drinking water in the lake area (Table 4).

Table 4. Water health risk of Puzhehei Lake

Sampling point		Chemical carcinogens								Non-carcinogen											
		Cd ($\times10^{-6}$)		Cr ($\times10^{-3}$)		As ($\times10^{-6}$)		R^c ($\times10^{-3}$)		NH_3-N($\times10^{-10}$)		Cu ($\times10^{-11}$)		Zn ($\times10^{-12}$)		Pb ($\times10^{-10}$)		Hg ($\times10^{-9}$)		R^n ($\times10^{-9}$)	$R_{总}$ ($\times10^{-3}$)
		R^a_{ig}	Average	R^a_{ig}	Average	R^a_{ig}	Average			R^b_{jg}	Average	R^b_{jg}	Average	R^b_{jg}	Average	R^b_{jg}	Average	R^b_{jg}	Average		
Leshui Cave (the upper reach)	Sampling 1	9.86	5.75	5.86	5.64	6.73	6.73	5.65		6.366	6.38	8.98	8.98	1.50	1.50	3.14	3.83	2.99	2.24	3.36	5.65
	Sampling 2	1.64		5.42		6.73				6.389		8.98		1.50		4.52		1.50			
Puzhehei Village (the middle reach)	Sampling 1	7.94	10.3	3.53	4.30	6.73	6.73	4.31		5.86	4.93	8.98	8.98	19.5	1.87	3.88	1.96	7.48	6.73	7.53	4.31
	Sampling 2	12.6		5.07		6.73				4.01		8.98		18.0		0.0321		5.99			
Puzhehei National Wetland Park (the lower reach)	Sampling 1	0.0274	0.0274	4.45	5.94	6.73	6.73	5.95		1.90	1.88	8.98	8.98	1.50	1.50	0.0321	0.0321	4.49	2.99	3.28	5.95
	Sampling 2	0.0274		7.43		6.73				1.87		8.98		1.50		0.0321		1.50			

4. Discussion

TN and NH3-N, TN and Pb, NH3-N and Pb, TP and Cd, Zn and Hg were significantly positively correlated, and the correlation coefficients were 0.965, 0.944, 0.908, 0.816 and 0.879, respectively, among which TN and NH3-N, TN and Pb, NH3-N and Pb have the strongest correlation. It can be seen that there was a significant correlation between TN, NH3-N and Pb, indicating that these three pollution indicators may be the main factors that cause water quality changes in Puzhehei Lake[12]. In addition, there was no significant correlation between other factors. But But interestingly, except for COD, there was a certain negative relationship between Cr and other 8 factors, which can be further analyzed in future research.

Table 5. Pearson correlation matrix between pollution indexes of Puzhehei Lake

	COD	TN	NH_3-N	TP	Zn	Pb	Cd	Cr	Hg
COD	1	0.078	0.222	0.44	-0.07	-0.146	0.644	0.114	-0.031
TN		1	0.965**	0.71	0.075	0.944**	0.294	-0.288	-0.066
NH_3-N			1	0.795	0.209	0.908*	0.5	-0.342	0.095
TP				1	0.577	0.52	0.816*	-0.518	0.438
Zn					1	0.036	0.681	-0.578	0.879*
Pb						1	0.126	-0.325	-0.033
Cd							1	-0.325	0.581
Cr								1	-0.7961
Hg									

Note: **significant correlation at the 0.01 level (two-tailed), * significant at the 0.05 level (two-tailed).

In the above conclusions, the middle reaches represented by Puzhehei Village had the worst water quality and the most serious water pollution, which was related to the population growth and the development of tourism service industry in this region in recent years. Specifically, Puzhehei Village is one of the important areas for the development of tourism in Puzhehei Lake, and its large lakeside belt has been converted into construction land, which has caused the water area in the middle reaches of Puzhehei Lake to shrink seriously [13]. At the same time, according to the sixth national census, the populations of Yuezhe Town, Shuanglongying Town and Badaoshao Yi Township where the three sampling points of Puzhehei Lake are located are 33,223, 75,190, and 31,345 respectively. This leads to relatively more non-point source pollution in this area, more domestic wastewater entering the lake, and relatively poor water quality. In response to the problem of water pollution in Puzhehei, Qiubei County of Yunnan Province has formulated the "Overall Plan for the Protection and Management of Puzhehei Lake Basin" to investigate the pollution sources of the lake. So far, 268 households and 308 fish ponds in the basin have been renovated. In addition, in view of the excessive health risks of chemical carcinogens in Puzhehei Lake water body, we should focus on the treatment of pollutants such as Cr and Cd in the future to ensure water safety in the basin.

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