Quantitative Evaluation of the Degree of Functional Damage of Dalinuoer Lake

Weigang Hao[1], Yongfu Wei[1], Quan Liu[2], Ji Ma[2], Zilong Liao[1], Xiaomin Xu[1], and Liping Cui[1]

[1]Institute of Water Resources for Pastoral Area, Ministry of Water Resources, Hohhot, Inner Mongolia, China

[2]Hulunbuir Hydrological Bureau, Hulunbuir, Inner Mongolia, China

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Abstract: This paper introduces a method to evaluate the damage degree of lake function based on the water pollution loss rate. According to data on the water quality of Dalinuoer Lake in China, this method is used to evaluate the damage degree of use function. The results show that many use functions of the Dalinuoer Lake are seriously damaged. The main problems include, there are too many nutrients in the lake, and the contents of TN and TP in water body exceed the standard.

1. Introduction

Dalinuoer Lake is the second largest fresh water lake in Inner Mongolia Autonomous Region of China and the most important migration channel for migratory birds in Northeast Asia. Dalinuoer Lake has a number of use functions, such as aquaculture, drinking water, living and tourism; it also has a very high ecological function, and is of great significance to the local environment. Water pollution leads to the reduction of environmental quality, which is mainly reflected in two aspects. First, it reduces the resource value of the water environment itself. Second, it reduces comfort services provided by the environmental system, and weakens the ecological service function of the environmental system itself.[1] Affected by the climate change and human activities, the water quality of Dalinuoer Lake is deteriorating, resulting in serious damage of use functions. According to the water quality of Dalinuoer Lake, this paper evaluates the damage degree of use functions, so as to provide a scientific basis for the management and protection of Dalinuoer Lake.

2. General Situation of the Study Area

Dalinuoer Lake is a plateau inland lake, located in Hexigten Banner, Chifeng City, Inner Mongolia Autonomous Region of China. It is located within 116°29′~116°45′E and 43°13′~43°23′N, with an altitude of 1226m. The lake basin is deep in the west and shallow in the east, with an average depth of about 6.7m and a water storage capacity of about 1.6 billion m3. Dalinuoer Lake has four supply rivers, all of which are inland rivers, namely the Gongger River, the Haolai River, the Liangzi River and the Shali River, with annual supply of 60.9 million m3. Dalinuoer Lake is a closed soda type brackish water lake. [2] The lake is rich in crucian carp and Leuciscus waleckii, and is the largest fishing base in Hexigten Banner. Dalinuoer Lake has a rich and diversified ecosystem, including lakes, grasslands, wetlands, woodland and sandy land. The wetland composed of inland rivers and lakes on the plateau centered on Dalinuoer Lake has been listed in the records of important wetlands in Asia.

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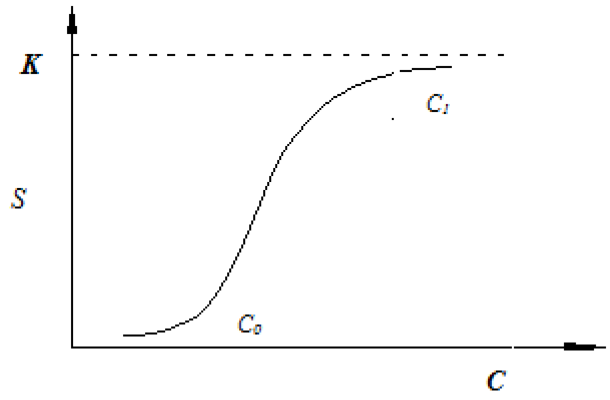

Fig.1 Pollution Loss -Concentration Curve.

3. Model of Water Pollution Loss

3.1 Evaluation of the Damage of Single Function Lake

James proposed the pollution loss - concentration curve, as shown in Figure 1, which is S-shaped. With the increase of concentration, the loss increases rapidly within a certain range, and the loss caused by water pollution tends to the limit to a certain extent. Suppose that there are n pollutants in the i function of lake. The loss of water caused by a pollutant can be described above [3]. The formula is as follows:

$$S = \frac{K}{1 + a \times \exp(-b \cdot c)} \tag{1}$$

In the formula, S is the economic loss caused by a pollutant to the water body; c is the concentration of a pollutant (mg/l); a and b are parameters determined by the characteristics of the pollutant, which can be determined by toxicology experiment or damage experiment; K is the amount or value of the functional resource.

R is defined as the ratio of the loss caused by the pollutant to the functional value K_i under a certain concentration of c, which is called the loss rate of the pollutant to the function, referred to as the pollution loss rate. Therefore, from formula (1) we can obtain:

$$R = \frac{S}{K} = \frac{1}{1 + a \times \exp(-b \cdot c)} \tag{2}$$

Generally, the pollution loss rate of the j-th pollutant to the i-th function of the lake can be written as follows:

$$R_{ij} = \frac{1}{1 + a_{ij} \cdot \exp(-b_{ij} \cdot c_j)} \tag{3}$$

Because a_{ij} and b_{ij} are parameters only related to the characteristics of pollutants and the use function of water body, they cannot be selected at will. They are objective. Table 1 shows the reference a_{ij} and b_{ij} values of several common pollutants.

When there are more than one pollutant in the water, the comprehensive loss rate is not simply the sum of the loss rates. When there are n independent pollutants, the comprehensive loss rate $R_i^{(n)}$ after subtracting the interactive part is:

$$R_i^{(n)} = R_i^{(n-1)} + (1 - R_i^{(n-1)}) \cdot R_{in} \tag{4}$$

This is a recurrence formula where $R_i^{(1)} = R_{i1}$. In the calculation, the concentration of each pollutant is substituted into formula (3) to calculate R_{ij}, the loss rate of each single pollution.

Afterwards formula (4) is used to calculate the comprehensive loss rate of pollution, $R_i^{(n)}$. In the calculation of $R_i^{(n)}$, the comprehensive loss rate of the two pollutants $R_i^{(2)}$ shall be calculated first, with $R_i^{(2)}$, we can suppose $R_i^{(3)} = R_i^{(2)}$ +[1- $R_i^{(2)}$]· R_{i3}. And so on until we figure out $R_i^{(n)}$.

Table 1 Reference Values of Parameters a and B.

Use function	Parameter	BOD5	TN	TP	Cd	Cr	volatile penol	As	Pb	cyanide	Hg
drinking water source	*a*	24569.50	368.00	368.00	985.00	985.00	274.90	985.00	2118.6	622.10	160.60
	b	1.83	5.25	52.52	459.52	4595.20	510.55	45.95	61.39	36.76	9674.00
swimming	*a*	5083.70	321.60	321.60	108.60	160.00	160.60	160.60	160.00	160.60	119.40
	b	1.31	4.70	47.13	18.56	9.77	96.74	9.67	9.67	9.67	1876.00
fishing	*a*	570.00	160.60	160.60	274.90	2118.60	622.10	985.00	9801.00	274.9	145.20
	b	0.44	0.48	4.84	204.22	61.37	367.60	45.95	91.90	204.22	3829.00
living	*a*	3909.70	368.00	368.00							
	b	0.92	2.63	26.26							
tourism	*a*	18895.60	799.40	799.40							
	b	1.31	4.18	41.77							
agricultural irrigation	*a*				274.90	274.90	274.90	108.60	274.90	274.90	274.90
	b				102.11	10.21	10.21	0.93	10.21	10.21	1021.10

The single pollution loss rate indicates the damage degree of pollutant j to function i. We take it as a single evaluation value of the damage degree of the pollutant to function i. The comprehensive pollution loss rate indicates the damage degree of i function when n pollutants coexist, which is the comprehensive evaluation value of the damage degree of this function.

3.2 Evaluation of the Damage Degree of the Water Environment Value of Multifunctional Lake

For lakes with m (m > 1) functions, the damage degree *Ri* of each function can be determined by the single function lake damage degree evaluation method [4]. If it is necessary to further integrate, we need to first determine the value of each function *Vi*, which can be evaluated by the principle of value evaluation in environmental economics, such as the cost of recovery, the cost of protection, human capital method and market value method. Taking $V_i / \sum_{i=1}^{m} V_i$ as the weight, the comprehensive evaluation value of damage degree of multifunctional lake is as follows.

$$R = \frac{V_1R_1 + V_2R_2 + ... + V_mR_m}{V_1 + V_2 + ... + V_m} \tag{5}$$

Obviously, when R is multiplied by the total value of lake $\sum_{i=1}^{m} V_i$, its value is the total loss of lake function value $\sum_{i=1}^{m} V_iR_i$. Therefore, *R* is the total loss rate of multi-functional lake caused by pollution, which objectively reflects the overall damage degree of water pollution to the water environment of the multi-functional lake. The evaluation results are not only related to the concentration and types of pollutants, but also to the use of water bodies.

3.3 Relationship between Lake Damage Degree and Water Quality Evaluation

Lake environment quality is directly related to the degree of lake environmental damage. Therefore, the pollution loss rate can be taken as the evaluation result of lake water quality at the same time [5]. The various water quality evaluation indexes and evaluation modes in the past have shortcomings of lacking clear physical significance and covering up or exaggerating the impact of some pollutants. The method proposed in this paper overcomes these shortcomings, and unifies the degree of lake damage with the evaluation of water quality, so that the water quality evaluation results also have clear physical significance.

4. Calculation of Water Pollution Loss Rate of Dalinuoer Lake

Water quality data from several monitoring points in Dalinuoer Lake were selected in 2017.

According to the National Environmental Quality Standard for Surface Water (GB3838-2002), BOD_5, TN, TP, Cd, Cr, volatile phenol, As, Pb, cyanide and Hg were selected as evaluation factors to calculate the pollution loss rate of single index and comprehensive pollution loss rate of Dalinuoer Lake under different use functions in 2017 with the formulas (3) and (4) respectively. Table 2 shows the calculation results.

Table 2 Rates of Pollution Loss of Different Functions of Dalinuoer Lake.

loss rate R (%)	BOD_5	TN	TP	Cd	Cr	volatile penol	As	Pb	cyanide	Hg	Compre-hensive loss rate
drinking water source	1.53	99.71	99.80	0.37	0.63	0.42	0.15	0.05	0.19	0.91	99.99
swimming	0.14	99.06	99.66	0.96	0.64	0.62	1.40	0.63	0.64	0.89	99.99
fishing	0.73	2.14	95.69	0.64	0.06	0.18	4.80	0.01	0.82	0.80	96.11
living	0.51	72.50	98.94								99.71
tourism	0.37	97.19	99.26								99.98
agricultural irrigation				0.48	0.38	0.36	0.99	0.37	0.38	0.38	3.30

It can be seen from table 2 that the water quality of Dalinuoer Lake is deteriorating. In addition to being used as agricultural irrigation water, the damages to its functions such as drinking water source, swimming water, fishery and breeding water, living environment water as well as tourism and landscape water are close to the upper limit. Its main pollutants come from nutrients TN and TP; the TP content is extremely high. However, heavy metals and toxic substances have no obvious damage to all functions of the lake, and the single pollution loss rates are no more than 5%.

5. Conclusion

The Dalinuoer Lake, which is a closed lake, is located in the arid and semi-arid high plain area. The annual precipitation is less than 400mm, but the annual evaporation is more than 1300mm. The water has no outlet; pollutants brought by rivers to the lake cannot be discharged, and the evaporation is far greater than the supply. The lake is shrinking year by year; water quality indicators are increasingly concentrated. The salt content of the lake water is increasing; the unreasonable management and over development of human beings make the water quality of Dalinuoer Lake even worse. According to the Environment Bulletin of Inner Mongolia Autonomous Region, the water quality of Dalinuoer Lake has been worse than class V for years, and the pollution degree is relatively heavy. Dalinuoer Lake is undergoing a long evolution process “which is from fresh water to semi salt water, and then to salt water and salt lake”.

In this paper, through the evaluation method of pollution loss rate, the degree of functional damage and the water quality evaluation of Dalinuoer Lake are unified, so that the evaluation results have a clear physical significance. It can be seen from the evaluation results that the damage degrees of multiple use functions of Dalinuoer Lake are close to the upper limit. The main problems are high contents of TN and TP in the water, especially the very high content of TP and the excessive nutrients. However, heavy metals and toxic substances do not cause more than 5% damage to all functions of the lake.

Dalinuoer Lake is a multi-functional lake with high ecological benefits in arid and semi-arid areas. The effective play of its lake functions will inevitably have a great impact on the ecology and social economy of the area. From above, we can see that the water quality of Dalinuoer Lake is deteriorating and the functions of the lake are seriously damaged; effective measures should be taken as soon as possible to manage the water quality.

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