Desalination and Water Treatment
www.deswater.com
doi: 10.5004/dwt.2021.27803

239 (2021) 118–125
November

Method of sustainable utilization of water resources in Lake Resort based on ecological footprint

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Received 17 August 2021; Accepted 23 September 2021

ABSTRACT

In order to improve the availability of water resources in Lake Resorts, a calculation method of water resources utilization based on ecological footprint was proposed. Based on the theory of ecological footprint, this method constructs the ecological footprint model. Based on the ecological footprint model, the water consumption of Lake Resort was calculated. The direct consumption coefficient and complete consumption coefficient are introduced to analyze the relationship between the influencing factors of water resources consumption in Lake Resort. Finally, with the support of the calculation results of multiple water resources constraints, the calculation results of water resources utilization in Lake Resort are obtained. The experimental results show that the proposed method has high accuracy and can complete the calculation of water resources available amount with a low cost.

Keywords: Ecological footprint; Lake Resort; Water resources; Available consumption; Consumption coefficient

1. Introduction

The concept of the ecological footprint model was proposed by Canadian economists in 1992. With continuous development, subsequent scholars have gradually improved the concept of the ecological footprint model [1–3]. The ecological footprint model including ecological footprint, ecological carrying capacity and ecological deficit (or surplus) concepts and indicators, ecological footprint is defined as the energy resources and the population in certain areas of production consumed and to absorb all the waste generated by these populations production of ecological water area required [4,5]. With the improvement of the quality of life, more and more people tend to travel to Lake Resorts. Therefore, it is necessary to study a calculation method of available water resources in Lake Resorts [6].

Tang et al. [7] proposed a method for calculating the available water resources in Lake Resorts based on the PSO optimized logistic curve. This method constructs a water resource state-pressure response model to determine the availability index system of water resources in Lake Resorts and adopts. The logistic curve simulates the availability of water resources in Lake Resorts, and finally uses the Logistic index formula to evaluate and calculate the available water resources in Lake Resorts, but the calculation accuracy of the water resources carrying capacity of this method is poor. Song et al. [8] proposed a method for calculating the amount of water resources available in Lake Resorts based on optimal configuration. This method uses a benefit-sharing algorithm to calculate the water use benefits of Lake Resorts and constructs an objective function with the goal of maximizing water use benefits [9–11]. The linear method is used to solve the objective function, and based on the result of the objective function, an optimal allocation model of the available water resources of the Lake Resort is constructed to complete the calculation of the available water resources of the Lake Resort, but the calculation cost of this method is relatively high. Chen et al. [12] proposed a calculation method for the amount of water resources available in Lake Resorts based on the entropy matter-element extension

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method. This method introduces the maximum closeness method to improve the traditional matter-element extension evaluation method to improve the matter-element extension method. Based on the extension evaluation method, the water resources carrying capacity of the Lake Resort is calculated, and the entropy method is used to determine the weight ratio of the factors affecting the water resources carrying capacity of the Lake Resort, and the calculation of the available water resources of the Lake Resort is completed. The calculation accuracy of the bearing capacity of this method still needs to be further improved [13,14].

In order to solve the problems of the above methods, the calculation method of available water resources in Lake Resort based on ecological footprint is proposed to realize the accurate and low-cost calculation of water resources available in Lake Resort.

2. Ecological footprint model

Ecological carrying capacity is defined as the capacity of ecological water resources that can be supplied to human beings in a certain region. In other words, the ecological footprint reflects the human consumption capacity of the natural ecosystem from the demand side, while the ecological carrying capacity reflects the supporting capacity of the natural ecosystem from the supply side. By comparing the two, if the ecological carrying capacity of a Lake Resort is greater than the ecological footprint, it shows that the ecological surplus shows that the pressure of humans on the water resources ecosystem in the region is within the ecological carrying capacity provided by the region, and it can be considered that the carving machine of human society is in a sustainable range [15–17]. On the contrary, if the ecological carrying capacity is less than the ecological footprint, it will show an ecological deficit and be in an unsustainable state. The ecological deficit or surplus reflects the utilization of natural resources, the security of the ecosystem and the sustainable development of the region.

2.1. Ecological footprint analysis method

The usable amount of water resources in Lake Resorts is a unit of measurement, which converts various material and energy consumption of human activities into biological production water resources in proportion, and measures human consumption from the perspective of ecological production water resources area occupation. The impact and impact of activities on the ecological environment of water resources reveal the environmental pressure state of the studied area and the crisis [18]. Therefore, ecological footprint analysis is considered to be closely linked to the theory of sustainable development and closely integrates human beings with the ecosystems they depend on and support.

- The ecological footprint calculation formula is:

$$E = N \times F = N \times \sum r_j \left(\frac{c_i}{p_i} \right) \quad (1)$$

where E is the total ecological footprint, N is the total population, F is the per capita ecological footprint, i is the consumption and input type of water resources, r_j is the equilibrium factor, j is the type of ecological water resources, c_i is the per capita consumption of the i-th water resources, and p_i is the global average production capacity of the i-th water resources.

The equilibrium factor is the ratio of the average potential productivity of an ecological water resource to the average production potential of all ecological resources on the earth. In this calculation, in order to ensure the comparability of the time series, the equilibrium factors of various ecological resources were selected as: cultivated land and construction land is 2.8, woodland and energy land is 1.1, grassland is 0.5, and water is 0.2 [19–22].

- Ecological carrying capacity is defined as the total amount of ecological water resources that can be supplied to humans in a region. To express the ecological capacity of water resources in the area, the formula for calculating the ecological carrying capacity of water resources in Lake Resorts is:

$$C = N \times e = N \times \sum a_j r_j y_j \quad (2)$$

where C represents the total carrying capacity of ecological water resources, N represents the total population, e represents the per capita ecological carrying capacity, a_j represents the area of per capita ecological water resources, r_j represents the equilibrium factor, and y_j represents the output factor. The output factor refers to the ratio of the average productivity of the j-type water resources in the Lake Resort area to the world average productivity.

In this calculation, the values of the yield factors are as follows: farmland and construction land is 2.3, grassland is 0.39, woodland and energy land is 0.91, and water area is 1.0 [11,23,24].

- The ecological deficit is formed when the total amount of water resources required for consumption exceeds the ecological footprint provided by the ecological carrying capacity. The formula for calculating the ecological deficit is:

$$D = E - C \quad (3)$$

where D represents an ecological deficit. If $D > 0$, it means that the ecological footprint is greater than the ecological carrying capacity, and there is an ecological deficit, which is not conducive to the development of water resources in the Lake Resort. If $D < 0$, it means that the ecological footprint is less than the ecological carrying capacity, and there is ecological surplus, indicating the development of water resources in the Lake Resort of eco-affordable range [25].

According to the above calculation results, the ecological footprint model is constructed as shown in Fig. 1.

3. Calculation of available water resources in Lake Resorts

3.1. Water consumption calculation

The water resources system of the Lake Resort is a relatively open cyclic system. Therefore, in the study of the

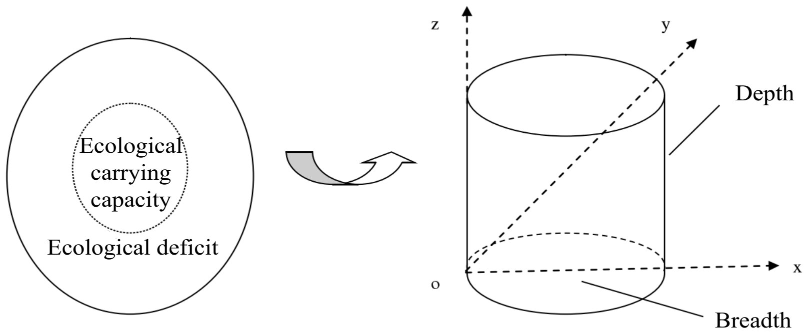

Fig. 1. Ecological footprint model.

available water resources of the Lake Resort, the water consumption demand of the ecological environment in the lake should be fully considered. Overall consideration of the ecological environment water demand in the Lake Resort and the water used for life, production and artificial ecological environment in the Lake Resort area, and the one-time maximum water consumption of the ecological environment and the artificial environment in the Lake Resort area is calculated under the condition of meeting the minimum demand for the ecological environment [26,27]. The calculation formula is:

$$W_{\mathrm{uw}} = W_{\mathrm{orl}} + W_{\mathrm{orp}} + W_{\mathrm{ore}} = W_{\mathrm{se}} \tag{4}$$

$$W_{\mathrm{ee}} = W_{\mathrm{ire}} \tag{5}$$

where W_{uw} represents the utilization of water resources in the Lake Resort area, W_{orl} represents the domestic water consumption of the residents in the resort area, W_{ore} represents the ecological environment water consumption in the Lake Resort area, W_{se} represents the water demand after the coordination of the Lake Resort ecosystem, and W_{ee} represents the Lake Resort area water after coordination ecosystem, W_{ire} represents lake water ecosystem environment.

There is a balanced output relationship between the total utilization and consumption of water resources in the lake ecological resort area, which is:

$$\sum_{j=1}^{n} x_{ij} + Y_i = X_i \left(i = 1,2,\ldots,n \right) \tag{6}$$

where $\sum_{j=1}^{n} x_{ij}$ represents the intermediate water consumption of the Lake Resort, Y_i represents the water output of the Lake Resort, and X_i represents the total output of water consumption.

In order to describe the relationship between the various influencing factors and water consumption in Lake Resorts, the direct consumption coefficient index is introduced, which is also called the intermediate technical coefficient. The calculation formula of the direct consumption coefficient is:

$$a_{ij} = \frac{x_{ij}}{X_j} \tag{7}$$

where a_{ij} represents the direct consumption coefficient, x_{ij} represents the water consumption i under the influence factor j, and X_j represents the water input volume under the influence j factor.

In order to grasp the relationship between the influencing factors of water resources consumption in the Lake Resort as a whole, the complete consumption coefficient is calculated on the basis of the above direct consumption coefficient. Denote the direct consumption coefficient matrix as A and the complete consumption coefficient matrix as $\bar{B}$, then the relationship between the two is:

$$\bar{B} = \left(I - A \right)^{-I} \tag{8}$$

where $\bar{B} = \left[\bar{b}_{ij} \right]_{n\times n}, \bar{b}_{ij}$ represents the complete consumption coefficient of the i-th influencing factor on the j-item influencing factor, $B = [b_{ij}]_{n\times n}$, b_{ij} represents the direct consumption coefficient of the i-th influencing factor on the j-item influencing factor, and $(I–A)^{-I}$ represents Leontief Inverse matrix.

Another index commonly used for the correlation between water resources consumption factors in Lake Resorts is the complete correlation coefficient, that is, the inductance coefficient DIF. The calculation formula of the inductance coefficient is:

$$\mathrm{DIF}_i = \frac{\sum_{j=1}^{n} \bar{b}_{ij}}{\frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} \bar{b}_{ij}} \tag{9}$$

The sensitivity index reflects the increase in water consumption in Lake Resorts. The greater the sensitivity coefficient, the greater the restraint on the use of water resources in Lake Resorts.

After introducing the direct consumption coefficient, the above formula is rewritten into the following form:

$$AX + Y = X \text{ or } X = \left(I - A \right)^{-1} Y \tag{10}$$

where A, X, Y represent the intermediate input coefficient matrix $A = [a_{ij}]_{n\times n}$, the total output row vector $X = [X_j]_{n\times n}$, and the final output column vector $Y = [Y_i]_{n\times n}$.

According to the above calculation results, the calculation formula for the total water consumption of the Lake Resort is:

$$Y_i = \sum_{k=1}^{4} Y_{ik} + \mathrm{EX}_i - \mathrm{IM}_i \tag{11}$$

where $Y_{ik}(k = 4)$ represents the factors affecting the water consumption of the Lake Resort, EX_i represents the transfer volume, and IM_i represents the transfer volume.

3.2. Calculation of available resources

According to the calculation results of the above water consumption, the available water resources of the Lake Resort are calculated.

- Constraints on the allocation of water resources in Lake Resorts

$$\max f_1(x) = \sum_{i=1}^{I} a_{1i}(t)x_{1i}(t) + \sum_{j=1}^{J} a_{2j}(t)x_{2j}(t) + \sum_{k=1}^{K} a_{3k}(t)x_{3k}(t) \tag{12}$$

where $f_1(x)$ is the water resource allocation function, $a_{1i}(t)$ is the water resource consumption of the primary industry in the resort, $a_{2j}(t)$ is the water resource consumption of the secondary industry in the resort, $a_{3k}(t)$ is the water resource consumption of the tertiary industry in the resort, $x_{1i}(t)$ is the water resource allocation amount of the primary industry in the resort, $x_{2j}(t)$ is the water resource allocation amount of the secondary industry in the resort, and $x_{3k}(t)$ is the water resource allocation amount of the tertiary industry in the resort.

- Minimize total regional water consumption

$$\min f_2(x) = \sum_{i=1}^{I} x_{1i}(t) + \sum_{j=1}^{J} x_{1j}(t) + \sum_{k=1}^{K} x_{1k}(t) \tag{13}$$

where $f_2(x)$ represents the minimization function of water consumption in the resort.

- Minimization of wastewater production coefficient

$$\min f_3(x) = \sum_{i=1}^{I} a_{1i}(t)b_{1i}(t)x_{1i}(t) + \sum_{j=1}^{J} a_{2j}(t)b_{2j}(t)x_{2j}(t) + \sum_{i=1}^{K} a_{3k}(t)b_{3k}(t)x_{3k}(t) \tag{14}$$

where $f_3(x)$ is the function of minimizing sewage discharge, $b_{1i}(t)$ is the sewage generation coefficient of the primary industry in the resort, $b_{1j}(t)$ is the sewage generation coefficient of the secondary industry in the resort, and $b_{1k}(t)$ is the sewage generation coefficient of the tertiary industry in the resort.

$$\min \sum_{i=1}^{I} a_{1i}(t)x_{1i}(t) + \sum_{j=1}^{J} a_{2j}(t)x_{2j}(t) + \sum_{i=1}^{K} a_{3k}(t)x_{3k}(t) \geq \min Z_1(t) \tag{15}$$

where $\min Z_1(t)$ represents the minimum planned value of sewage discharge in the Lake Resort.

- Resource constraints

$$\begin{cases} \sum_{i=1}^{I} x_{1i}(t) + \sum_{j=1}^{J} x_{2j}(t) + \sum_{k=1}^{K} x_{3k}(t) \leq \max Z_2(t) \\ -W_6(t)P(t) - W_e(t) \\ x_{1i}(t) \geq D_{1i}(t) \\ x_{1j}(t) \geq D_{2j}(t) \\ x_{1k}(t) \geq D_{3k}(t) \end{cases} \tag{16}$$

where $\max Z_2(t)$ is the maximum water resource tolerance limit of the resort, $W_6(t)$ is the comprehensive water quota of the resort, $P(t)$ is the total number of people in the resort, $D_{1i}(t)$ is the minimum water demand of the primary industry, $D_{2j}(t)$ is the minimum water demand of the secondary industry, and $D_{3k}(t)$ is the minimum water demand of the tertiary industry.

$$\sum_{i=1}^{I} Q(t)\, x_{1i}(t) \geq \min Z_3(t) \tag{17}$$

where $Q(t)$ represents the utilization function of water resources per square, and $Z_3(t)$ represents the minimum planned value of the total output of water resources in the Lake Resort.

$$\sum_{i=1}^{I} a_{1i}(t)b_{1i}(t)\, x_{1i}(t) + \sum_{j=1}^{J} a_{2j}(t)b_{2j}(t)\, x_{2j}(t) + \sum_{k=1}^{K} a_{3k}(t)b_{3k}(t)\, x_{3k}(t) \leq \max Z_4(t) \tag{18}$$

where max $Z_4(t)$ represents the maximum capacity of water resources in the resort.

- Social and environmental constraints

$$\sum_{i=1}^{I} a_{1i}(t)\, c_{1i}(t)\, x_{1i}(t) + \sum_{j=1}^{J} a_{2j}(t)c_{2j}(t)\, x_{2j}(t) + \sum_{k=1}^{K} a_{3k}(t)\, c_{3k}(t)\, x_{3k}(t) \leq \max Z_5(t) \tag{19}$$

where $c_{1i}(t)$ represents the water resources available content of the primary industry, $c_{2j}(t)$ represents the water resources available content of the secondary industry, $c_{3k}(t)$ represents the water resources available content of the tertiary industry of the resort, and $\max Z_5(t)$ represents the maximum water resources content of the resort.

- Other constraints

$$x_{1i}(t), x_{2j}(t), x_{3k}(t) > 0, i = 1,2,\ldots,J; k = 1,2,\cdots,K \quad (20)$$

Synthesize the above calculation formula, combine the objective function and each constraint condition to construct the calculation function of the available water resources of the Lake Resort area:

First, the above-mentioned raw data is averaged, and there are n sub-factors X_0 that have a certain correlation with the main factor $X_1, X_2, \ldots, X_n$, and both X_0 and $X_1, X_2, \ldots, X_n$ are data sequences composed of m indicators, then:

The sequence of parent factors was as follows:

$$X_0 = \left[X_0(1), X_0(2), \ldots, X_0(m)\right] \quad (21)$$

Sub-factor sequence:

$$X_i = \left[X_i(1), X_i(2), \ldots, X_i(m)\right] \quad (22)$$

The dimensionless processing is carried out under the action of the averaging operator D, so that the order of magnitude of each factor is roughly equal:

$$X_i D = \left[X_i(1)D, X_i(2)D, \ldots, X_i(m)D\right] \quad (23)$$

$$x_i(k)D = \frac{x_i(k)}{x_i(1)} \quad (24)$$

where $X_i D$ represents the image of i and D under the averaging operator, which is referred to as the initial value image.

Calculate the available coefficient based on the averaged data:

$$\varepsilon_{i0}(k) = \frac{\min_i \min_k \left|x_0(k) - x_i(k)\right| + \rho \max_i \max_k \left|x_0(k) - x_i(k)\right|}{\left|x_0(k) - x_i(k)\right| + \rho \max_i \max_k \left|x_0(k) - x_i(k)\right|} \quad (25)$$

where ρ represents the resolution coefficient. The formula for calculating the final available water resources is:

$$r_{0i} = \frac{1}{m}\sum_{k=1}^{m} \varepsilon_{0i}(k) \quad (26)$$

Through the above calculation, the calculation of water resources available quantity of Lake Resort based on ecological footprint is completed.

4. Experimental verification

In order to verify the application performance of the proposed calculation method for the availability of water resources in Lake Resorts, comparative verification experiments were carried out. The experiment is a simulation experiment. The experiment environment is: the number of virtual machine groups is 3, the main nodes are haddoop01, haddoop02, and haddoop03, the experimental system is CentOS6.5, the hard disk capacity is 20 GB, the memory capacity is 4 GB, and the CPU is 2 cores [28].

In the above experimental environment, the experimental comparison scheme is set as follows: Taking the calculation accuracy of water resources carrying capacity, calculation accuracy of water resources available amount and calculation cost as the experimental comparison indexes, the proposed method is compared with the methods by the studies of Tang et al. [7] and Song et al. [8].

4.1. Calculation accuracy of water resources carrying capacity

The results of accuracy comparison of the three methods are shown in Fig. 2.

It can be seen from Fig. 2 that in the increasing experimental time, the calculation error of water resources carrying capacity of the proposed method is always lower than that of the two literature comparison methods. The maximum calculation error of the proposed method is not more than 0.2, while the maximum error of the methods by the studies of Tang et al. [7] and Song et al. [8] is 0.43 and 0.78. Therefore, it fully shows that the proposed method has high accuracy in water resources carrying capacity calculation.

4.2. Calculation accuracy of available quantity

The comparison results of the calculation accuracy of the available water resources of the three methods are shown in Fig. 3.

It can be seen from Fig. 3 that the calculation accuracy of the proposed method is higher, and the highest calculation accuracy can reach 98%, while the highest calculation accuracy of the two literature comparison methods is 55% and 79%, respectively.

4.3. Calculate the cost

Table 1 shows the comparison results of the calculation cost of the available water resources of the three methods.

Analysis Table 1 shows that in the process of many experiments, the calculation cost of the proposed method is always lower than that of Tang et al. [7] and Song et al. [8] method. The average calculation cost of the proposed method is 0.183 ten thousand yuan, that of Tang et al. [7] method is 0.536 ten thousand yuan, and that of Song et al. [8] method is 0.63 ten thousand yuan. Therefore, it fully shows that the proposed method can reduce the calculation cost on the basis of improving the calculation accuracy [29].

5. Conclusion

In order to improve the calculation accuracy of the available water resources in Lake Resorts, a calculation method based on ecological footprint was proposed. The performance of this method is verified from both theoretical and experimental aspects. The method has high accuracy and efficiency in the calculation of water resources available in Lake Resort. Specifically, compared with the method based on PSO optimization logistic curve, the calculation error of water resources carrying capacity of this method is

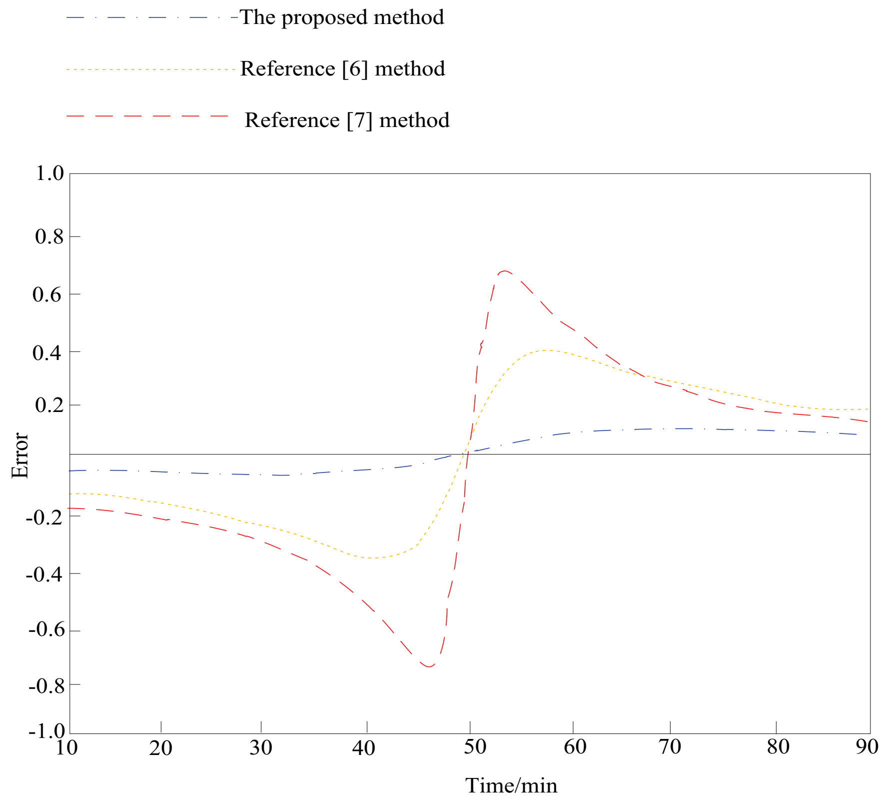

Fig. 2. Comparison results of calculation accuracy of water resources carrying capacity.

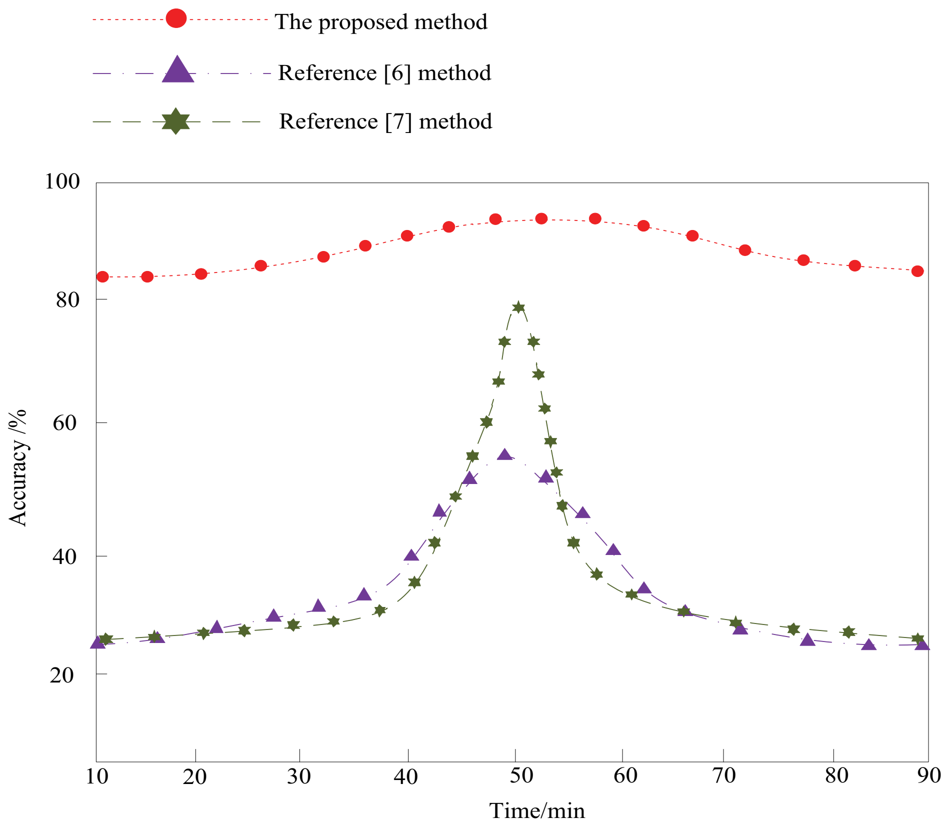

Fig. 3. Comparison results of calculation accuracy of available water resources.

Table 1
Comparison of available calculation cost

Number of experiments	Available amount calculation cost/ten thousand yuan		
	Proposed method	Tang et al. [7] method	Song et al. [8] method
1	0.21	0.56	0.68
2	0.19	0.47	0.71
3	0.14	0.63	0.62
4	0.20	0.51	0.65
5	0.16	0.42	0.59
6	0.17	0.58	0.63
7	0.22	0.49	0.55
8	0.21	0.55	0.49
9	0.16	0.59	0.67
10	0.17	0.56	0.71
Average value	0.183	0.536	0.63

significantly reduced, and the maximum calculation error is less than 0.2; Compared with the method based on optimal allocation, the calculation accuracy of water resources available quantity is significantly improved, and the maximum calculation accuracy can reach 98%. Therefore, the calculation method based on ecological footprint can better meet the requirements of Lake Resort water resources utilization calculation. In future research work, it is necessary to further improve the calculation accuracy to ensure a sufficient supply of water resources in the Lake Resort.

Acknowledgement

The research was supported by: Science and Education Joint Project of Hunan Natural Science Foundation: Evaluation and Promotion Research in Landscape Attraction of Leisure Agriculture in Southern Hunan based on Tourism Motivation Theory(No. 2021JJ60075).

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