Ecological Water Demand of Rivers in the Dongting Lake Basin

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Abstract The study of ecological water demand in rivers has been a research hotspot in recent years. In this paper, selecting the widely used research methods (Tennant method, minimum monthly flow average measurement method, monthly average flow guarantee rate method, monthly minimum flow method, $7Q_{10}$ improvement method), the ecological water demand of rivers in the Dongting Lake basin was studied. Combined with the hydrological characteristics of the basin water system, the calculation results by the above five methods were averaged. It was obtained that the ecological water demand of rivers in the basin from April to September and from October to next March was 3.876×10^9 and 3.425×10^9 m^3, respectively. The annual ecological water demand was 7.301×10^9 m^3, accounting for about 11.46% of the average annual runoff in the basin. The research results can provide a basis for regional water resource utilization planning and are of great significance for maintaining the health of river ecosystems.

Key words Dongting Lake basin; Ecological water demand; Calculation method; Tennant method; Guarantee rate method

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Ecological water demand of rivers refers to the minimum river runoff that can maintain the ecological system of a river from destruction, ensure the ecological health of the river within a certain period of time, without considering the impact of human activities on water quality and water resource utilization, and ensure that the basic ecological environment functions of the river are not lost, namely the minimum threshold at which a river can ensure its normal operation[1]. Based on years of hydrological measurement data, several representative and suitable methods that meet the requirements of river ecosystem protection are selected from numerous methods to analyze the ecological water demand of rivers[2]. Combined with the actual situation in the region, the ecological water demand of rivers can be obtained, which can provide a theoretical basis for the development and utilization planning of water resources in the region and is of great significance for maintaining the stability of river ecosystems.

The water system of the Dongting Lake basin is mainly located at 27°39′ - 30°20′ N, 110°40′ - 113°34′ E, with a drainage area of about 262 800 km^2. It is a famous fertile land. The Dongting Lake basin is located in the subtropical monsoon climate zone, and the water system in the basin experiences significant changes in abundance and drought throughout the year. The measured data have shown that there is a significant difference in monthly runoff of river systems in the basin, with the minimum and maximum monthly runoff differing by several to more than ten times. Especially during the dry season, the runoff decreases sharply, river pressure increases, and the supply of ecological water demand is insufficient, which has an impact on industrial and agricultural water use in areas near the water system in the basin. If rivers maintain this pressure for a long time, the basic functions of their ecosystems will be disrupted, and their self-healing capabilities will also be lost, leading to severe degradation of river ecosystems.

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1 Research methods and data

1.1 Research methods The research methods for ecological water demand of rivers mainly include hydrological methods, hydraulic methods, habitat methods, comprehensive methods, environmental functional design methods, *etc.* Taking into account the advantages and disadvantages of various methods mentioned above, and referring to a large number of cases in current research of ecological water demand, hydrological methods were chosen in this paper.

1.2 Data The data used in this paper was from the series of the *China River Sedimentation Bulletin* (2002 - 2018), and the average annual runoff of water system in the Dongting Lake basin was represented by the series of 1950 - 2020. The runoff variation of water system in the Dongting Lake basin was closely related to precipitation, with significant changes in annual abundance and scarcity. The data from three national hydrological control stations, Xiangtan on the Xiangjiang River, Taoyuan on the Yuanjiang River, and Chenglingji at the outlet of the Dongting Lake, were selected to calculate the ecological water demand of rivers.

2 Calculation methods and estimated results of ecological water demand for rivers

Based on the situation of the Dongting Lake basin, referring to the widely used research methods, Tennant method, guarantee rate method, minimum monthly flow average measurement method, monthly minimum ecological runoff calculation method, and $7Q_{10}$ improvement method were selected in this paper.

2.1 Tennant method In the Tennant method, the recommended values of river flow are divided into 7 criteria based on the determined percentage of average annual flow, namely 1 criterion of the optimal range and the other 6 criteria. Table 1 was a description of the flow situation.

In the Tennant method, a year is divided into two calculation periods, mainly based on the seasonal requirements of aquatic organisms for the environment, namely the reproductive patterns of fish. It is designated as the high water period from April to September, and the low water period from October to next March.

Table 1 Description of river flow status %

Time	Optimal range	Excellent	Very good	Good	General or poorer	Poor or minimal	Very poor
October – next March	100	40	30	20	10	10	0 – 10
April – September	100	60	50	40	30	10	0 – 10

2.2 Guarantee rate method The main steps for calculating the ecological water demand of rivers using the guarantee rate method[3] are as follows: firstly, based on the historical annual runoff data of hydrological stations over the years, a frequency calculation table for annual runoff of hydrological stations is drawn. Secondly, the moment method is used to calculate and determine the required parameters. Then, Pearson III type is used to determine the runoff frequency curve, mainly adjusting the line shape through visual estimation to obtain the optimal parameters. According to the calculation, the ecological water demand of rivers with the levels of optimal range 100%, excellent 60%, very good 40%, good 30%, and average or poorer 10% is calculated at the guarantee rates of 90%, 75%, and 50%.

2.3 Minimum monthly flow average measurement method The minimum monthly flow average measurement method is to take the multi-year average of the minimum monthly average measured runoff as the basic ecological water demand of the river. The minimum monthly flow average measurement method calculates the ecological water demand of rivers based on the measured runoff during periods of low or no rainfall, taking into account issues such as the growth needs of organisms and purification and pollution of rivers.

2.4 Monthly minimum ecological runoff calculation method The monthly minimum ecological runoff calculation method divides the historical hydrological flow data of rivers into a monthly runoff series from January to December, and takes the minimum ecological runoff in the past 12 months as the minimum ecological runoff for that month, thus obtaining the minimum ecological runoff for each month and composing the annual minimum ecological runoff[4].

2.5 $7Q_{10}$ improvement method The $7Q_{10}$ method originated in the United States, using the average water volume of the driest continuous 7 d with a guarantee rate of 90% as the design value for the minimum river flow. Later, scholars made improvements to the $7Q_{10}$ method based on actual situations, and the improved method is also known as the $7Q_{10}$ improvement method[5].

3 Comparative analysis of research results on ecological water demand of rivers in the Dongting Lake basin

According to the above calculation method, the basic ecological water demand of rivers in the Dongting Lake basin can be analyzed to obtain the following results (Table 2). When using the Tennant method, the basic ecological water demand of rivers was 40.36×10^8 m^3 from April to September, and 8.79×10^8 m^3 from October to next March. When using the seasonal frequency calculation method, the basic ecological water demand of rivers in the basin was 78.32×10^8, 94.04×10^8, and 114.05×10^8 m^3 under the guarantee rates of 90%, 75%, and 50%. When calculated using the minimum monthly flow average measurement method, the basic ecological water demand was 73.42×10^8 m^3. When using the monthly minimum ecological runoff calculation method, the basic ecological water demand was 66.39×10^8 m^3. The basic ecological water demand was 35.71×10^8 m^3 when calculated using the $7Q_{10}$ improvement method.

Due to differences in the biological species and hydrological characteristics of water system in the basin, the average for ecological water demand of rivers was taken by integrating the above methods, and the ecological water demand calculated by each method was obtained. After calculation, the ecological water demand of rivers in the Dongting Lake basin was 38.76×10^8 m^3 from April to September, and 34.25×10^8 m^3 from October to next March. The annual ecological water demand was 73.01×10^8 m^3, accounting for about 11.46% of average annual runoff in the basin.

Table 2 Comparison of ecological water demand by five methods 10^8 m^3

Hydrologic station	Tennant method		Seasonal frequency calculation method			Minimum monthly flow average measurement method	Monthly minimum ecological runoff calculation method	$7Q_{10}$ improvement method	Mean
	April – September	October – next March	90%	75%	50%				
Xiangtan	6.86	1.82	14.31	16.94	20.18	13.32	11.85	7.80	13.30
Taoyuan	6.70	1.42	15.08	17.16	19.71	12.10	10.69	4.79	12.52
Chenglingji	26.80	5.55	48.93	59.94	74.16	48.00	43.85	23.12	47.19
Total	40.36	8.79	78.32	94.04	114.05	73.42	66.39	35.71	73.01

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3 Conclusions

In this paper, based on MODIS NDVI and sunshine data from 2000 to 2019, using the mathematical statistical methods, the monthly variations in vegetation and sunshine hours in the Beijiang River basin were primarily analyzed, as well as the response relationship between the two. The results showed that:

(1) The annual average NDVI of the basin was 0.58. In terms of intra-annual distribution, it was the lowest in February (0.41), gradually increased from February to September, reached its highest in September (0.72), and then gradually decreased from September to next February. The overall NDVI of the basin showed a fluctuating upward trend (with a linear trend of 0.022/10 a). In terms of monthly trends, there was a slight decrease in April and June, followed by a rapid increase in July, August, September, October, and December. In terms of spatial distribution, the overall NDVI of the basin was relatively high from May to October, with minor differences in most areas. From November to next April, regional differences became more pronounced. Areas with lower NDVI were primarily distributed in the southern and central-northern river valley plains.

(2) The average annual sunshine hours was 1 595.80 h, but it varied greatly from year to year, with the highest value being 1 844.85 h (in 2004) and the lowest value being 1 382.59 h (in 2012). The annual sunshine hours generally showed a downward trend, with a trend rate of −4.2 h/a. Regarding the sunshine hours for each month, it ranged from 175 to 200 h from July to October; from 65 to 100 h from January to April; and from 110 to 145 h for the remaining months. The sunshine hours in most months showed a downward trend, with significant decreases in May and November (passing the 0.05 of confidence test). Correlation analysis indicated that there was a positive correlation between NDVI and sunshine hours, with a stronger correlation from January to June.

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4 Conclusions

In this paper, the ecological water demand research comprehensively considered factors such as the annual runoff variation characteristics of rivers, the minimum runoff under the drought limit of rivers, and the minimum monthly runoff measured over many years in terms of theory and method. These methods are representative and meet the requirements of protecting river ecosystems in practice. Therefore, the average values obtained through these methods have certain reference value for water resource utilization planning in the Dongting Lake basin.

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