Spatial Analysis of Water Resources Carrying Capacity based on Available Amount of Effective Water Resources: A Case Study of Taizhou City, China

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Abstract: In view of the uneven distribution of water resources in time and space and the prominent problems of water environment, this paper puts forward a calculation method of Available Amount of Effective Water Resources considering the guaranteed rate of incoming water and the rate of reaching the standard of water quality. Taking Taizhou City of Zhejiang Province as an example, the Water Resources Carrying Capacity was analyzed. The results show that the current water resources carrying capacity in Taizhou is generally in a loose state, but there is a serious problem of uneven spatial distribution. On the Spatial Balance Principle, strengthening water saving from the demand side and increasing the available water resources from the supply side are important measures to improve the carrying capacity and promote spatial balance.

1 INTRODUCTION

Water resources are an indispensable precious resource for human survival and development, but the amount of water resources is limited. How much economic and social scale can be supported by water resources in a region has always been one of the core contents of water resources research, and it is also an important constraint factor for the development of a region (Ren et al., 2016; Dou et al., 2015; Xia & Zhu, 2002). Chinese researchers first put forward the concept of Water Resources Carrying Capacity (WRCC) since the late 1980s, which is a threshold for measuring regional economic and social development restricted by water resources (Zhao et al., 2021; Yang et al., 2019). However, there are many discussions about the concept and calculation method of water resources carrying capacity in academic circles, and a complete theoretical and methodological system has not yet been formed (Peng et al., 2021).

The existing quantitative calculation methods of WRCC include empirical formula method, comprehensive evaluation method and system analysis method (Yang et al., 2015; Song et al., 2011). The empirical formula method is relatively simple and easy to operate, and its shortcoming is that it pays less attention to the relationship among resources, environment, and economy. The mathematical theory of comprehensive evaluation method is deeply applied, but the selection of indicators and the determination of weights are both important and difficult. The system analysis method considers the mutual feedback relationship between water resources and economy, society, and ecology, but the deficiency is that the calculation method is complicated (Cheng et al., 2018).

Based on relevant research, this paper puts forward an analysis method of water resources carrying capacity based on available water resources for areas with uneven spatial and temporal distribution of water resources and outstanding water environment problems, and makes an example calculation in Taizhou City, Zhejiang Province.

2 MATERIALS AND METHODOLOGY

Taizhou City is in the southeast coast of Zhejiang Province, with an area of 9411 km^2 and an average annual surface water resource of 8976 million m^3. Jiaojiang River is the main river in Taizhou, and there are many small rivers flowing into the sea alone. According to the third national water

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resources survey and evaluation, Taizhou is divided into six water resources four-level subareas, namely Yongan River (YR), Shifeng River (SR), Ling River and Left bank of Jiao River (LRLJR), Wenhuang Plain (WP), Yuhuan Island (YI), Xiangshan Port and Sanmen Bay (XPSB).

The WRCC usually refers to the population scale supported by the maximum load that water resources can bear on the economy and society under the premise of meeting the reasonable water consumption of river ecological environment in the foreseeable period, combining with other resources, intelligence, and technology [6-8]. From the definition, the core of WRCC is the number of people supported by water resources in a region with the cooperation of other resources. Therefore, the calculation method of regional WRCC is as follows.

$$WRCC = \frac{W}{q} \quad (1)$$

where q is per capita water consumption; W is Available Amount of Effective Water Resources (AAEWR) and could be calculated as follows.

$$W = \alpha_1 \alpha_2 \bar{W} \quad (2)$$

where $\bar{W}$ is the average amount of water resources for many years; α_1 is availability of water resources and could be obtained by dividing the annual water resources availability after frequency elimination by the multi-year average; α_2 is the reduction factor of water resources quality and defined as follows:

$$\alpha_2 = \frac{\sum L_i F_i}{\sum L_i} \qquad F_i = \begin{cases} 0 & \textit{not meet the standard} \\ 1 & \textit{meet the standard} \end{cases} \quad (3)$$

where L_i is the river length of water functional area; F_i refers to the compliance of water functional areas (WFA). Based on the natural attributes (resource conditions, environmental conditions and geographical location) and social attributes (development and utilization status, water quality and quantity demand) of water resources, WFA divides the use functions of water bodies in various river basins in Zhejiang Province according to certain indicators and standards, and reasonably determines its water quality protection objectives, so as to ensure that the development and utilization of water resources can bring into play the best economic, social and environmental benefits. Meanwhile, Water Resources Overload Degree (WROD) is also proposed to measure the current situation of water resources carrying potential as follows:

$$WROD = \frac{P}{WRCC} = \begin{cases} > 1 & \textit{not overload} \\ < 1 & \textit{overload} \end{cases} \quad (4)$$

where P is the total population corresponding to the evaluation time. The larger the WROD value, the greater the bearing potential.

3 RESULTS

For the parameter α_1 mentioned above, taking YR as an example, the availability of water resources with 50%, 75%, 90% and 95% guarantee rates are 32%, 24%, 17% and 15%, respectively. Obviously, 50% of the incoming water conditions are too optimistic, while 90% of the guaranteed water conditions are too harsh. This time, 75% of the guaranteed water availability is used to analyze the water resources carrying capacity. Meanwhile, Taizhou City is divided into 113 WFA. In 2017, 73 WFA were monitored, and the water quality of 55 WFA reached the target requirements. According to the catchment area and length of WFA, the water quality compliance rate of WFA was weighted and averaged, and the parameter α_2 was obtained. Further, the results shown in the following Table 1 can be obtained by calculation.

From the perspective of Taizhou city, its WROD is 0.90, indicating that the city's WRCC is generally loose, and there is still a surplus carrying capacity of nearly 700,000 persons, leaving room for Taizhou's future economic and social development. However, from the perspective of each water resources subareas, YR, SR and XPSB have strong WRCC, and the WROD of YR is as low as 0.25, which is the highest in the city. The water resources carrying capacity of WP and YI, located in the southeast coast of Taizhou, is seriously overloaded, among which the former is the core area of Taizhou's economic and social development. However, the WROC is as high as 2.70, and the AAEWR are far from supporting the economic and social development of this region.

Table 1: The WRCC of Taizhou City (2017).

Subareas	Topography	Area km^2	$\bar{W}$ 10^8 m	α_1	α_2	W 10^8 m^3	q m^3·person^-1	WRCC 10^4 person	P 10^4 person	WROD
YR	Hilly	2357	23.2	0.235	1.00	5.45	303.7	179.5	44.8	0.25
SR	Hilly	1485	13.05	0.286	1.00	3.73	288.3	129.52	51.6	0.4
LRLJR	Hilly Plain	1485	14.42	0.328	0.54	2.56	280.4	91.26	86.8	0.95
WP	Hilly Plain	2101	20.72	0.422	0.37	3.22	275.6	116.82	316	2.7
YI	Hilly Plain	576	4.51	0.353	0.48	0.76	297.7	25.47	44.1	1.73
XPSB	Hilly Plain	1408	13.86	0.227	0.84	2.65	182.8	144.83	68.5	0.47
Taizhou		9412	89.76	0.305	0.66	18.37	270.1	680.07	611.8	0.9

4 DISCUSSIONS

Water resources are an important basic resource for the development of national economy. To realize the sustainable development of economy and society, the prerequisite is to realize the sustainable utilization of water resources and enhance the supporting capacity of water resources for the development of national economy. From the previous analysis, due to the mismatch between water resources endowment and the layout of cultivated land, population and productivity, Taizhou City has insufficient carrying capacity in some regions and surplus in others. In the future, it is necessary to follow the Spatial Balance Principle. On the one hand, it takes the regional WRCC as a rigid constraint to scientifically plan the scale, structure, and layout of economic and social development; On the other hand, by strengthening water saving on the demand side and increasing AAEWR on the supply side, the WRCC can be improved, and the balance between water resources and regional population and economy can be promoted. Taking subarea of WP as an example, there are three ways and measures to improve the WRCC.

(1) Improve water quality. The α_2 in WP is 0.37, which indicates that the water quality in the water functional area is poor. If the water quality compliance rate in the water functional area is improved by strengthening pollution control and α_2 will be increased to 0.9 in the future, the WRCC in WP can be increased to 2.86 million people, and WROD can be reduced to 1.11, correspondingly.

(2) Advocate water-saving actions. The annual per capita water consumption in WP is 275.6 m3/person, who is basically the same as the average level of the whole city. If the per capita water consumption is reduced by 10% by strengthening water saving in the future, the WRCC in WP can be further increased by 3.18 million people, and the annual water resources are basically not overloaded at the current level.

(3) Implement water diversion project. WP is originally a river network area, and its water resources development and utilization conditions are relatively poor. After the completion of the Taizhou North-to-South Water Transfer Project (i.e., from the YR Basin with relatively rich water resources to the WP), it can increase the available water resources by 100 million m3. At that time, the WRCC of WP can be further increased by 3.58 million people, and the WROD from overload to looseness, increased to 1.13, leaving a certain development space for the economy and society.

5 CONCLUSIONS

In this paper, a calculation method of AAEWR considering the guaranteed rate of incoming water and the standard rate of water quality is put forward, and based on this, the WRCC of Taizhou City, Zhejiang Province is analyzed. The research shows that the current WRCC is generally in a loose state, but there is a serious problem of uneven spatial distribution, especially the WRCC in the subarea of WP located in the southeast coast is serious. On the Spatial Balance Principle, it is suggested that measures such as improving water resources quality, advocating water-saving actions, and implementing water diversion projects should be taken to improve the WRCC in WP and promote the balance between water resources and regional population and economy.

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