

Estimation of regional groundwater resources carrying capacity in Yangtze River Economic Belt

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Abstract. It is of great significance to evaluate the groundwater resources carrying capacity, for understanding the basic situation of regional groundwater resource availability and utilization, establishing a monitoring and warning mechanism for resources and environment carrying capacity, and supporting the research oriented to national spatial planning. In this paper, groundwater resources carrying capacity is proposed based on analysis of the quantity, quality and ecological feature of groundwater in Yangtze River Economic Belt, an evaluation methodology is established respectively from background and status of carrying capacity. Results show that integrated carrying capacity is medium in this region. The number of cities with strong, medium-strong, medium, medium-weak, and weak integrated carrying capacity are 27, 28, 51, 15, and 8 respectively. Cities with strong and medium-strong integrated carrying capacity are mainly located in Middle-Lower of Yangtze River, Huang-Huai-Hai Plain and Sichuan Basin. Cities with medium-weak and weak integrated carrying capacity are mainly located in coastal areas of Jiangsu and Zhejiang provinces, Sichuan red layer area, north of Sichuan Plateau, and Jinsha River basin.

1 Introduction

The research on the carrying capacity of resources and environment usually takes natural resource and environmental system as the carrying subject and social or economic development as the carrying object, to study the support of natural resource and environmental system to social or economic system in a certain geographical space [1]. As an important part of resources, it is of great significance to evaluate the groundwater resources carrying capacity, for understanding the basic situation of regional groundwater resource availability and utilization, establishing a monitoring and warning mechanism for resources and environment carrying capacity, and supporting the research oriented to national spatial planning.

In the process of studying the restrictive effects of water resources on ecological carrying capacity, population carrying capacity or sustainable development, a series of similar concepts have been developed in foreign countries, such as *Water Available* [2], *Water stress index* [3], *Water Scarcity Index* [4], *Ecologically Sustainable Water Resource* [5-6], but hardly carried out research on the subject of water resources carrying capacity

In the early 1990s, Shi Yafeng put forward the "water resources carrying capacity" when he studied the restrictive effects of water resources on the ecological environment and socio-economic system in the arid regions of northwestern China [7]. After more than 30 years of research, the carrying capacity of water resources has been independently developed, which mainly includes three viewpoints: 1) the largest scale of water resources

supporting population or economic and social development [7]; 2) the ability of water resources to support regional social and economic development [8]; 3) water resources development capacity [9]. The research method gradually started from a single index, static analysis to a system multi-objective, dynamic comprehensive analysis.

In the late 1990s, as the proportion of groundwater supply in China increased rapidly, land subsidence and other ecological environmental problems caused by excessive exploitation of groundwater. Research on the carrying capacity of groundwater resources attracted much attention. Scholars carried out a lot of useful explorations about groundwater carrying capacity in the North China Plain, the Guanzhong Plain, the Karst areas in Guizhou, and other large-scale irrigation districts [10-12].

This paper intends to take Yangtze River Economic Belt as the research region, combining groundwater resources endowments, development and utilization conditions, and related ecological and environmental issues, to carry out regional groundwater resources carrying capacity evaluation, and to determine background of groundwater resources carrying capacity and overloading degree.

2 Research region

The Yangtze River Economic Belt covers 11 provinces including Shanghai, Jiangsu, Zhejiang, Anhui, Jiangxi, Hubei, Hunan, Chongqing, Sichuan, Yunnan, and Guizhou, covering an area of approximately 2,052,300 km², accounting for 21.4% of the total land area of China.

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There are various types of groundwater in this region. Loose rock pore water is most abundant, followed by karst water, clastic rock fissure-pore water and bedrock fissure water. The natural replenishment of groundwater resources amounts to 34,500 million m³/a, accounting for 40% of the national total; the exploitable resources are about 130.3 billion m³/a, accounting for 34% of the total in China.

The quality of groundwater is always good, except for the distribution of saline water along the coast of Jiangsu and Zhejiang, and the distribution of high-fluorine water in the Huaibei-Subei area and Sichuan-Guizhou area. Over the past several years, the amount of groundwater exploitation has been about 9 billion m³/a, and the exploitation rate is about 7%. However, in some parts of this region, especially the Huaibei Plain and some areas in the middle-lower reaches of the Yangtze River, due to the rapid social and economic development, the utilization of groundwater has been at a relatively high level for a long period, resulting in land subsidence issues.

3 Methods and data

3.1 Methods

Carrying capacity of groundwater resources are defined as the ability of regional groundwater resources to ensure local social and economic development under the premise that the development of groundwater does not damage the ecology and stability of the geological environment under a certain period of technical and economic conditions [13]. The evaluation of the carrying capacity of groundwater resources emphasizes the concept of equal emphasis on quantity, quality, and ecology, bottom line of ensuring quality, stability of the ecology and the geological environment.

According to the theory of resource and environment carrying coordination [14], the objects and contents of groundwater resources carrying capacity mainly include:

(1) The object of background of carrying capacity - groundwater resources. The endowment of groundwater resources is considered mainly from two core natural attributes of quantity and quality.

(2) The object of state of carrying capacity - the relationship between groundwater resources and socio-economic systems, which should be focused on the current status of the utilization of groundwater under the condition

of regional socio-economic development, and the adverse effects on water quality, ecology, and geological environment.

(3) The integrated Carrying capacity, which reflects the current quantity and quality of groundwater resources and the level of the ability to maintain the ecological environment to ensure social and economic development through the background and state results.

Based on the above theory, this article intends to evaluate the carrying capacity of groundwater resources in the Yangtze River Economic Belt. Starting from the calculation of single indexes such as the modulus of groundwater exploitable resources and the degree of exploitation, the initial background and state is given out. Then the initial background evaluation is revised by level of groundwater background quality, and the initial state is revised by degree of land subsidence. If the grade of revised index evaluation result is poor or high, the initial result will drop one level. Based on the final results of the background and state, the integrated carrying capacity is determined according to Table 2.

The evaluation methods of above index are as follows:

(1) Module of exploitable groundwater resources

module of exploitable groundwater resources represents the amount of exploitable groundwater resources per unit area. The amount of exploitable groundwater resources is usually defined as the amount of groundwater that can be continuously exploited and induce few environmental problems during the mining process [15]. It is one of the concepts commonly used by researchers to characterize the amount of groundwater resources. This index emphasizes the calculation of the amount of groundwater should can be exploited under the premise of ensuring ecological safety.

After analyzing data of this index, the classification standards for the 5 levels are given (Table 3), which represent the amount of groundwater resources in the region is richer, rich, medium, poor and poorer.

(2) Degree of groundwater exploitation

The degree of groundwater exploitation refers to the ratio of the amount of groundwater exploitation to the amount of exploitable groundwater resources. This index comprehensively reflects the utilization of groundwater resources, and can fully reflect the support of groundwater for social economic system. This index is currently one of the widely used indexes.

Corresponding to the three levels of state, the degree

Table 1 Evaluation index system of regional groundwater resources carrying capacity

Type of index	Background	State
Basic index	module of exploitable groundwater resources	degree of groundwater exploitation
Revised index	level of groundwater background quality	degree of land subsidence

Table 2 Criteria of comprehensive groundwater resources carrying capacity

Level of integrated carrying capacity	Level of background				
	high	Medium-high	medium	Medium-low	low
surplus	strong	strong	medium-strong	medium	medium-weak
balanced	strong	medium-strong	medium	medium-weak	weak
overloaded	medium-strong	medium	medium-weak	weak	weak

Table 3 Classification of module of exploitable groundwater resources

Level	High	Medium-high	Medium	Medium-low	Low
Module of exploitable groundwater resources ($\times 10^4 \text{m}^3/\text{km}^2 \cdot \text{a}$)	≥ 10	[7.5, 10)	[3.5, 7.5)	[2, 3.5)	< 2

of groundwater exploitation is divided into three levels—low, moderate, and over-exploitation. Among them, the degree of groundwater exploitation is greater than 100%, that is, the amount of groundwater exploitation exceeds the amount of groundwater exploitable resources, which is over-exploitation; referring to the analysis standard for the degree of groundwater exploitation in various provinces in the new round of groundwater resources evaluation, 70% is taken as the critical value. Therefore, when the degree of groundwater exploitation is between 70%-100%, it is defined as moderate. The degree of exploitation is less than 70% is defined as low.

(3) Level of groundwater background quality

The level of groundwater background quality represents the quality of groundwater in the original conditions. By considering the basic chemical composition and typical elements of groundwater, the distribution of groundwater with high chemical composition content and background value is analyzed, and the area percentage is used to reflect the level of groundwater background quality. Salt content, arsenic, fluoride, and iodide are selected as the main indicator. *Groundwater Quality Standard (GBT14848-2017)* and *Drinking Water Hygiene Standard (GB5749-2006)* [16-17] are referred to judge whether the groundwater belongs to high background groundwater.

(4) Degree of land subsidence

Degree of land subsidence refers to the geological phenomenon in which the underground loose rock formations are consolidated and compressed due to natural factors or human engineering activities and cause the ground elevation to decrease in a certain area. Human activities are an important factor in inducing high-speed land subsidence. Huge and long-term exploitation of groundwater is most closely related to land subsidence, especially in Yangtze River Delta, North China Plain, Fen-Wei Basin [18]. The degree of land subsidence is expressed by the proportion of the area where the land subsidence rate is greater than 10mm/a.

The classification standard for revised indexed are divided as below (Table 4).

3.2 Data

The evaluation of carrying capacity of groundwater in Yangtze River Economic Belt is carried out with the city as the evaluation unit. The amount of groundwater exploitable resources is based on the New Round of Groundwater Resources Evaluation of China (1999-2002), and is updated based on the latest results of groundwater resources evaluations in various regions. The data of exploitation of groundwater is from the provincial water conservancy yearbooks in recent years. The distribution of groundwater with high chemical component content and

background values and the land subsidence rate come from the *Map of Groundwater Environment in China* and *Map of Land Subsidence in China*, which were published in 2018 [18,19].

Table 4 Criteria of revising indices of groundwater resources carrying capacity

Level	low/good	medium	high/poor
level of groundwater background quality	$< 10\%$	[10%, 38%)	$\geq 38\%$
degree of land subsidence	$< 12\%$	[12%, 28%)	$\geq 28\%$

4 Results and discussion

4.1 Background of groundwater resource carrying capacity

The modulus of the exploitable groundwater resources in the Yangtze River Economic Belt is $63,800 \text{ m}^3/\text{km}^2 \cdot \text{a}$. Generally speaking, the abundance of groundwater resources is at a medium level, but the modulus in different regions varies greatly. 32 high level of cities are mainly in Jiangsu, Hubei, Anhui, and Hunan Provinces; 23 medium-high level of cities are mainly in Guizhou, Hubei, Jiangsu, Jiangxi, and Hunan Provinces; 48 middle level of cities are mainly in Yunnan, Zhejiang, Hunan, and Sichuan Provinces; 15 medium-low level of cities are mainly in Sichuan and Yunnan Provinces; 8 low level of cities are mainly distributed in Sichuan and Zhejiang Province. It can be seen that groundwater in cities of the lower and medium reaches of the Yangtze River, Huang-Huai-Hai Plain is mainly pore water, with good exploited conditions, the modulus of exploitable resources is significantly higher than that of other regions. While in Jinsha River basin area of Yunnan Plateau and Sichuan red layer area, the groundwater is mostly karst or fissure water, and the exploited conditions are not good, therefore the modulus of exploitable resources is obviously low.

There are 3 cities with poor groundwater background quality in the Yangtze River Economic Belt, respectively city of Yancheng, Nantong and Lianyungang. They are all located in the coastal area. High-salinity groundwater and high-fluorine water are widely distributed, affecting background of groundwater quality.

For these 3 cities, the initial level of background of groundwater resource carrying capacity is reduced by one level. After correction, there are respectively 27, 28, 51, 15, and 8 cities with high, medium-high, medium, medium-low, and low level of cities in the Yangtze River Economic Belt.

4.2 State of groundwater resource carrying capacity

All cities of Yangtze River Economic Belt have a degree of groundwater exploitation less than 70%, which means the levels of state are all surplus. The degree of groundwater exploitation in some areas is relatively high. For example, groundwater resources in red layer area of Sichuan are relatively poor, but a large amount of groundwater needs to be exploited to solve the problems of agricultural production and urban and rural residents. Huaibei Plain has abundant groundwater resources and good exploited conditions, groundwater has been over-exploitation in some area, obvious depression cones of karst water have formed.

The results of the degree of land subsidence in all cities of Yangtze River Economic Belt are medium and low, which means that the state of groundwater resource carrying capacity of all cities in this region are surplus.

4.3 Integrated groundwater resource carrying capacity

The number of cities with strong, medium-strong, medium, medium-weak, and weak integrated carrying capacity are 27, 28, 51, 15, and 8 respectively. Cities with strong and medium-strong integrated carrying capacity are mainly located in Middle-Lower of Yangtze River, Huang-Huai-Hai Plain and Sichuan Basin. Cities with medium-weak and weak integrated carrying capacity are mainly located in coastal areas of Jiangsu and Zhejiang provinces, Sichuan red layer area, north of Sichuan Plateau, and Jinsha River basin.

Result shows that, in the Yangtze River Economic Belt, number of cities with strong, medium-strong, medium, medium-weak, and weak integrated carrying capacity are 23.26, 34.81, 97.11, 24.79, and 243,200 km², accounting for 11.39%, 17.04%, 47.54%, 12.13% and 11.90% respectively. Among them, the area with strong and medium-strong carrying capacity accounts for 28.43%, mainly distributes in the lower and middle reaches of the Yangtze River, the Huang-Huai-Hai area or the plains, basins, and low hilly mountains of the Sichuan Basin. The areas with weak and medium-weak carrying capacity accounts for 24.04%, mostly distributes in the eastern coast, the red layer area of Sichuan, the northern Sichuan Plateau, and the Jinsha River Basin. About half of this region has a medium carrying capacity.

5 Conclusions

(1) Among 126 cities in the Yangtze River Economic Belt, 27 have strong groundwater resource environmental carrying capacity, and 28 are medium-strong, accounting for 28.53% of this region. It is mainly distributed in the lower and middle reaches of the Yangtze River, the Huang-Huai-Hai area, and the plains, basins and low hilly mountains of the Sichuan Basin. There are 8 with weak carrying capacity and 15 with medium-weak carrying capacity, accounting for 23.96% of this region. They are mostly distributed in the eastern coast, Sichuan red layer area and northern Sichuan plateau, and Jinsha River basin. 49 cities have a medium carrying capacity, accounting for 47.51% of this region.

(2) The degree of groundwater exploitation in the Yangtze River Economic Belt is very low. In the past, the rate of land subsidence in urban areas caused by the concentrated utilization of groundwater has generally slowed down. Therefore, the main factor affecting the carrying capacity in this region is the quantity of groundwater at present. To improve the carrying capacity of regional groundwater resources, we should focus on strengthening the construction of groundwater supply projects in water-scarce areas, and the control of total water consumption and total sewage emission. Meanwhile, we should strengthen the treatment of environmental problems caused by unreasonable exploitation of groundwater in same places, such as water pollution treatment, land subsidence treatment, etc.

(3) The total amount of water resources in the Yangtze River Economic Belt is very rich. The average of total amount in recent years is about 1,276.4 billion m³. And the amount of surface and ground water resources are 1,257.1 billion and 345.6 billion m³ respectively. There are about 620,000 m³ water resources per kilometers in this region, which is 2.1 times of the national average. However, in some areas, such as Chengdu Plain, Central Yunnan Plateau, Central Guizhou Region, Heng-Shao arid area, Ji-Tai Basin, the northern and central part of Hubei hilly area, the southern part of Hunan region, the northern part of Anhui Plain, as well as some areas in the middle and lower reaches of the Yangtze River, Groundwater is still an important strategic water resource for the reason of lacking transit water resources. To improve the carrying capacity of regional groundwater resources, the construction of groundwater supply projects in water-scarce areas should be strengthened, total water consumption and intensity, total sewage emission should

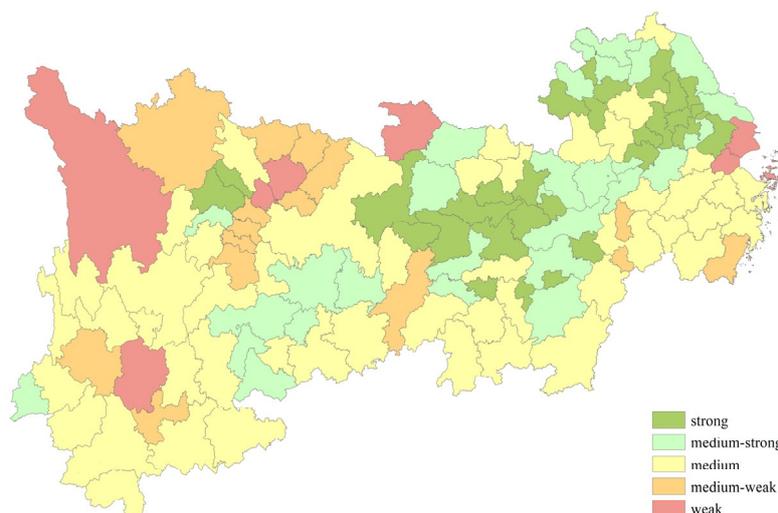


Fig.1 Results of groundwater resource carrying capacity in Yangtze River Economic Belt

be controlled, and treatment for water pollution and land subsidence should be implemented.

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