Study on grading system of water resources carrying capacity base on grey entropy weight clustering method in Henan

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Abstract. Water resources carrying capacity is an important indicator for evaluating the sustainable use of regional water resource. It is very important to evaluate regional water resources carrying capacity from systemic perspective which was a benefit for scientific management of water resources and protection of regional ecological environment. A water resources carrying capacity grading system was established based on water resource-water ecology-economy and society system. Using grey entropy weight clustering method which could make full use of data information to quantitatively calculate the water resources carrying capacity of Henan Province from 2001 to 2020. The results showed that water resources carrying capacity in Henan was upward trend with the carrying capacity grade rising from class IV to Class I from 2001~2020, which indicates that the water resources carrying capacity had been improved significantly. There were some indicators including total industrial wastewater discharge, urban sewage treatment rate, irrigation water consumption per hectare of farmland and water consumption of ten-thousand-yuan GDP identified as the main influencing factors limiting the improvement of water resources carrying capacity in Henan Province by using obstacle degree function analysis.

Keywords: Water resources carrying capacity; grey entropy weight clustering; influencing factors; Henan province

1 Introduction

The shortage of water resources would lead to the deterioration of the ecological environment and have an adverse effect on production and habitation. Water resources carrying capacity is a primary indicator to evaluate regional water resources security and constituting a significant part of regional natural resources carrying capacity [1-3]. It determines the comprehensive development and scale of a country or region. Quantitative grading evaluation of water resources carrying capacity is vital to optimize water resources allocation and support the sustainable development of region [4].

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Henan Province, located in the middle and lower reaches of the Yellow River, is an important city in the Yellow River basin. Its economic development and ecological function play an outstanding role in the Yellow River basin. With the rapid social development and economic growth, the water consumption and pollutant discharge in Henan Province are increasing continuously, and the ecological environment is increasingly disturbed by human beings. These reasons all lead to the deterioration of water resources carrying capacity in Henan Province. Therefore, it is necessary to evaluate regional water resources carrying capacity from systemic perspective which considering comprehensively from water resource-water ecology-economy and society system, so as to achieve high-quality and harmonious social development [5].

Since the 1980s, many studies on water carrying capacity have been carried out [4-7]. Previous studies established an evaluation index system with factors from water resources, economic society and ecological environment, and quantitative analysis carrying capacity by using entropy weight method or analytic hierarchy process method. However, these studies have not mined enough information contained in the indicator. In this study, a comprehensive grading evaluation method combining grey clustering and entropy weight was established to make full use of the fluctuation information of the index matrix which consists of dynamically assign weights to the indicators. Then calculate the possibility cluster of annual water resources carrying capacity and form the grading evaluation of water resources carrying capacity in different years. It is suitable for uncertain systems with small samples and little information for the further consideration of the index value. And the main influencing factors of water resources carrying capacity in Henan were determined by using obstacle degree function analysis. Based on the study results, recommendations are presented for the utilization of water resources in Henan Province.

2 Materials and Methods

2.1 Study area

Henan Province is located in the middle and lower reaches of the Yellow River. The river system in this province is developed including Yangtze River, Huaihe River, Yellow River, Haihe River. The annual average water resources in Henan Province are 40.35 billion m^3, but the per capita water resources are 383m^3, which is only about 20% of the national average in China [8]. Henan Province is a major grain producing area in China and rich in mineral resources. It is also an area of rapid economic development in the Yellow River Basin with the prominent ecological function. With climate change and rapid social development, regional water uses conflicts have become increasingly prominent. The shortage of water resources and the degradation of ecological environment have become the limiting factors for the sustainable development of Henan Province [9].

2.2 Evaluation index system and data sources

Water resources carrying capacity is mainly constrained by the factors from water resources system, ecological environment system and social system. And water resources carrying capacity has temporal and spatial characteristics, ecological characteristics and social characteristics. Spatiotemporal characteristics refer to the maximum amount of water resources consumed at a certain regional scale. The ecological characteristics include the development and utilization of water resources to reach renewable water resources, water environment quality to meet the corresponding use function and the needs of water ecosystem biodiversity; social characteristics refer to improving the water resources carrying capacity in by optimizing management and improving the technology level of water resources utilization. Based on the scientific, comprehensive and realizable principles, the evaluation index system of water resources carrying capacity in was established from three aspects (Table 1). There are 15 indicators in the index layer, which can be divided into positive and negative types. For the positive index, the higher the index value, the better the evaluation index.

Table 1. Evolution index system of water resources carrying capacity in Henan province

Serial Number	Criterion layer	Index layer	Meaning	Index type
1	Water resources System	Water resources per capita /m^3	Showing the state of regional water resources	positive
2		Utilization rate of water resources development/%	Showing the utilization of regional water resources	negative
3		Water production modulus (10^4 m^3/km^2)	Showing the total output and distribution of water resources	positive
4		Water supply modulus (10^4 m^3/km^2)	Showing regional water use intensity	negative
5		Precipitation/mm	Showing the overall climate water resources and distribution	positive
6	Ecological environment system	Forest coverage rate /%	Showing the status of water resources renewal	positive
7		Change rate of wetland area /%	Showing the regional water resources purification capacity	positive
8		Ecological water consumption /100 million m^3	Showing the demand of ecological environment for water resources	positive
9		Proportion of surface water quality sections with or better than Class III /%	Showing regional water environment capacity	positive
10		Total wastewater discharge /tons	Showing regional water pollution discharge	negative
11	Economic	Irrigation water per hectare of farmland (m^3/ hectare)	Showing the level of regional irrigation water	negative

12	and social system	Water consumption of ten-thousand-yuan GDP ($m^3/10^4$ yuan)	Showing the coordination degree of water resources and economic development	negative
13		Leakage rate of urban water supply network /%	Showing the efficiency of urban water supply	negative
14		Permanent resident urbanization rate /%	Showing the level of local social development	negative
15		Population density	Showing the population pressure per unit land area	negative

The source of data is mainly collected from the Statistical yearbook of Henan province, the Statistical Yearbook of China Urban and Rural Construction and Bulletin on the State of Henan Province's Ecological Environment from 2001 to 2020.

2.3 Method

The method of grey entropy weight clustering.

Quantitative evaluation methods for water resources carrying capacity mainly include empirical formula method, comprehensive evaluation method and systematic analysis method, among which quota method, principal component analysis method and entropy weight method are common evaluation methods [10]. The entropy weight method is a common objective valuation method with little influence on subjective factors, and the evaluation results are more reliable [11-13].

The Value of evaluation index data is uncertain which could be to as the grey number. According to the grey system theory, the Possibility Function can be used to determine the probability of different value intervals for each indicator, and the uncertain information contained in the value of the indicator can be fully used. According to the values of grey weight reuniting class coefficient, the cluster objects are classified. And the water resources carrying capacity level is determined by the maximum grey weight reuniting class coefficient. The specific calculation steps are as follows:

(1) Calculate the gray value of index f_{ijk}.

In this study, the exponential whitening function is used as the possibility function. f_{ijk} is the possibility function value which also is regarded as gray value of index i for standard j, n is the number of indicator standard intervals and for this study n is 4.

For the gray value of the first criterion of the indicator:

$$f(x_{ij})_i^1 = \begin{cases} e^{coef\frac{level_1 - x_{ij}}{level_n - level_1}} & , x_{ij} \geq level_1 \\ 1 & , x_{ij} < level_1 \end{cases} \tag{1}$$

For the gray value of the k (k=1, 2, … n-1) criterion of the indicator:

$$f(x_{ij})_i^k = \begin{cases} e^{coef\frac{level_1 - x_{ij}}{level_n - level_1}}, & x_{ij} < level_{k-1} \\ 1, & level_{k-1} \leq x_{ij} < level_k \\ e^{coef\frac{level_k - x_{ij}}{level_n - level_1}}, & x_{ij} \geq level_k \end{cases} \tag{2}$$

For the gray value of the n criterion of the indicator:

$$f\left(x_{ij}\right)_i^n = \begin{cases} e^{coef\frac{x_{ij}-level_n}{level_n-level_1}} & ,x_{ij} < level_n \\ 1 & ,x_{ij} \geq level_n \end{cases} \quad (3)$$

Where level k is the critical value of the evaluation standard k, and level1＜level2＜…＜level$n$.

(2) Calculate the clustering weight of indicator i in the year j by using the entropy weight method, $w_{ij}(j=1,2\ldots m)$.

$$p_{ijk} = \frac{f_{ijk}}{\sum_{k=1}^{n} f_{ijk}} \quad (4)$$

$$S_{ij} = -\frac{1}{lnn}\sum_{k=1}^{n} p_{ijk} ln p_{ijk} \quad (5)$$

$$w_{ij} = -\frac{1-S_{ij}}{N-\sum_{i=1}^{N} S_{ij}} \quad (6)$$

(3) Calculate the grey weight reunion class coefficient d_{jk}.

$$d_{jk} = \sum_{i=1}^{N} f\left(x_{ij}\right)_i^k * w_{ij}, j = 1,2,\ldots,m; k = 1,2,\ldots,n \quad (7)$$

(4) Determine the water resources carrying capacity grading for year j.

$$\max_{1\leq k\leq n}\{d_{jk}\} = d_{jk}^{*} \quad (8)$$

The water resources carrying capacity level of year j corresponds to gray class k.

Obstacle degree of indicator identification.

The obstacle degree analysis could quantitatively identify the main influencing factors of the water resources carrying capacity in Henan Province. It is very useful for scientific management and sustainable utilization of water resources. The specific calculation steps are as follows:

$$R_j = r_j \cdot w_i \quad (9)$$

Where r_j is the weight of indicator j, w_i is target weight of indicator j in the criterion layer which i belongs to.

$$P_j = 1 - a_j \quad (10)$$

Where a_j is the evaluation value of indicator in j year.

$$A_j = \frac{P_j \cdot R_j}{\sum_{j=1}^{15}(P_j \cdot R_j)} \quad (11)$$

Where A_j is the obstacle degree of indicator.

3 Results & Discussion

3.1 Analysis of water resources carrying capacity grading in Henan Province from 2001 to 2020

The change of water resources carrying capacity in Henan Province from 2001 to 2020 was calculated by using grey entropy weight clustering method. As shows in the Table 2, the water resources carrying capacity of Henan Province has been effectively improved, which increased from mainly grade III in 2001-2007 to mainly grade II in 2008-2020. And the class of water resources carrying capacity was stable at I ~ II. It indicates that the carrying capacity of water resources in Henan Province can basically meet the needs of economic-social and ecological environment development, which has a great relationship with the rational utilization and scientific management of water resources in recent years. According to the current situation, the carrying capacity of water resources in Henan Province will be further improved in the next period, and the ecological environment will also maintain a good condition.

Table 2. Annual grading table of water resources carrying capacity in Henan province

year	the grey weight reunion class coefficient	gray class k	resources carrying capacity level	year	the grey weight reunion class coefficient	gray class k	resources carrying capacity level
2001	0.5176	4	IV	**2011**	0.6804	2	II
2002	0.5445	3	III	**2012**	0.6903	2	II
2003	0.5992	1	I	**2013**	0.6021	2	II
2004	0.6228	3	III	**2014**	0.7443	2	II
2005	0.5110	3	III	**2015**	0.6384	2	II
2006	0.6956	3	III	**2016**	0.5947	2	II
2007	0.7277	3	III	**2017**	0.6238	1	I
2008	0.8471	2	II	**2018**	0.6433	2	II
2009	0.7052	2	II	**2019**	0.5815	1	I
2010	0.7397	1	I	**2020**	0.7711	1	I

3.2 Analysis on the main influencing factors of water resources carrying capacity in Henan Province

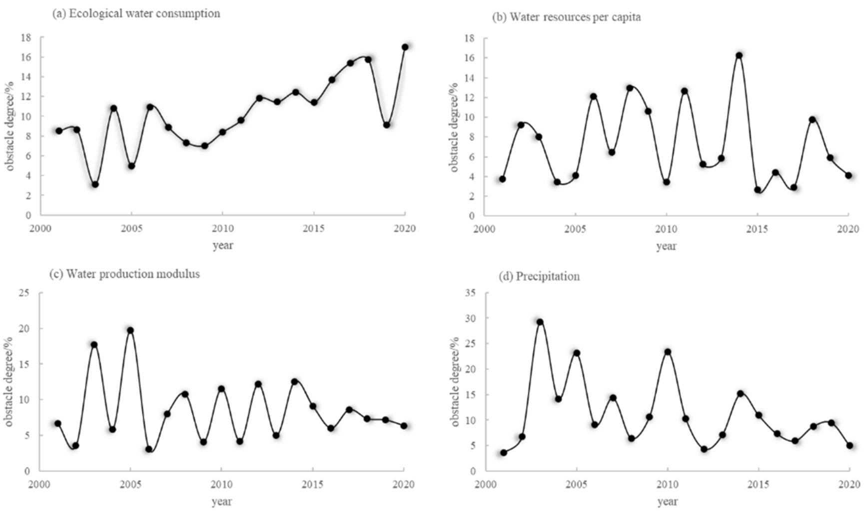

Fig. 1. Variation of obstacle degree value of main evaluation indicators for water resources carrying capacity in Henan Province

In order to find the weak links in the utilization and management of water resources in Henan Province, it is necessary to identify the main influencing factors of water resources carrying capacity by using obstacle degree analysis. The obstacle degree value of each index in Henan Province from 2000 to 2020 is calculated by using the obstacle degree function. By ranking the obstacle degree of the indicators, the top 4 high frequency indicators were identified as the main influence indicators. These indicators are ecological water consumption, water resources per capita, water production modulus and precipitation. As shows in the Figure 1, the obstacle value of Ecological water consumption indicator shows an increasing trend over time which indicates that the ecological environment has an increasingly important impact on the carrying capacity of water resources. And the obstacle values of water resources per capita, water production modulus and precipitation which belon to the criterion layer of water resources system all show a downward trend which belonged to the criterion layer of water resources system. It proves that the carrying capacity of water resources is closely related to the regional water resources background. Rationalizing the development and utilization of regional water resources is the main way to improve the carrying capacity of water resources in the future.

4 Conclusions

There are a lot of uncertainties and inaccuracies in the evaluation of water resources carrying capacity, which are both fuzzy and gray. Therefore, grey entropy weight clustering method is established by using the exponential possibility function to evaluate the carrying capacity of water resources. This method takes into account the characteristics of uncertainty in the standard division of indicators and the change of importance caused by the year fluctuation in the grading evaluation process. The grey entropy weight clustering calculation method can further use the data information of the evaluation indicators. It evaluates the regional development situation more comprehensively and objectively. And it is worth noting that the research on the relationship and mechanism between water resources, ecology and socio-economic system is worth exploring.

This study analysed the water resources carrying capacity of Henan Province from 2001 to 2020 by using the grey entropy weight clustering method. The results show that the water resources carrying capacity of Henan Province has increased from grade IV to grade I, and the carrying capacity of water resources has been significantly improved. Ecological water consumption, Water resources per capita, Water production modulus and Precipitation were identified as the main restricting the carrying capacity of water resources in Henan Province. In the future, the utilization of water resources in Henan Province should focus on protecting the ecological environment and promoting the scientific management of water resources, which has important guiding significance for water resources management in Henan Province. Based on the current situation evaluation, the multi-level optimization of water resources is also a very realistic research direction.

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