Regional water resources carrying capacity index system evaluation model and its application

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Abstract. Water carrying capacity assessment is to reveal the relationship between water resources, population, and economy, fully use water resources, and make economic development go hand in hand with protection of water resources, which simultaneously promote sustainable social and economic development. Based on the analysis of water resources carrying capacity defined, according to the measure of the demand for sustainable use of water resources, the paper combines the principle of selecting evaluation, uses combination of quantitative and qualitative analysis method to prefer indicators, in order to meet the maximum importance, representativeness, certainty and independence of indicators, then establishes 20 evaluation index system from three aspects of socio-economic, ecological environment and water resources systems. Based on the existing research results, combine the social and economic development level and characteristics of water resources carrying capacity assessment, regional water resources carrying capacity is divided into five levels: good, better, normal, poorer and poor. Set pair analysis method is proposed to evaluate the system, which can be described some certainty and uncertainty, and fully reflect the unity of opposites certainty and uncertainty system. Compared with traditional evaluations such as expert scoring method, fuzzy comprehensive evaluation method, gray clustering evaluation method, principal component analysis and factor analysis method, set pair analysis method can objective reflect the real situation of the evaluation and is simple to calculate and more workable. Finally, Gaochun District, which located in the southwest of Jiangsu Province, China, is select as a case study area. Consider the future direction of social and economic development, certain engineering and non-engineering measures can significantly improve the local water resources carrying capacity.

Introduction

Because of uneven distribution of water resources, with the rapid development of the growing population and the social economy, water shortages and deteriorating water quality has become the "bottleneck" factor of constraint sustainable socio-economic development. Situation cannot carry their own social and economic development of water resources in many cities has occurred. Sustainable development of water resources carrying capacity is an important part in the variety of natural resources carrying capacity of a country or a region, is essential for comprehensive development of a country or region. To solve the problem of water shortages, to achieve sustainable social and economic development in the region, we must first in-depth analysis of the carrying capacity of local water resources, providing water resources to support decision-making basis for socio-economic development and regional planning.

The purpose of the evaluation of the water resources carrying capacity is to reveal the relationship between water resources and population, fully rational utilize water resources, make economic development and protection of water resources, then promote sustainable social and economic development. Although some scholars at home and abroad have been research water resources carrying capacity, made some research results, such as Harris (1999) studied the agricultural production regional water resources carrying capacity of agriculture, the result as a measure of regional development potential [1]. Munther (2000) study the perspective of urban water resources carrying capacity, and integrate it into urban development planning [2]. In our country, some scholars study the water resources carrying capacity [3]. Zhou Lin (2007) using principal component analysis

study the water resources carrying capacity of Jiangmen City [4]. Yang Guang (2009) use Manes River Basin as a typical arid region, comprehensive value basin water resources carrying capacity through establish matter-element model [5]. Chang Jin (2013) proposed a projection pursuit classification model for water resources carrying capacity has been studied [6]. However, due to the complexity of the relationship between interconnected systems of water resources and the support of social and economic systems, water resources carrying capacity and sustainable development is not clear, analysis and evaluation of water resources carrying capacity is also mainly limited to static analysis, not reflect the characteristics and development of the target area. Set Pair Analysis is a new method of uncertainty analysis proposed by scholar Zhao Keqin [7], from the overall research and analysis on the intrinsic relationship between the local system, the method is clear concept, structure simple, calculation simple, easy to operate, has been widely used in the evaluation of water resources system [8,9]. In this paper, aim at the regional water resources carrying capacity, use set pair analysis method to evaluate water resources carrying capacity assessment provides a new approach.

Regional water resources carrying capacity

The concept of carrying capacity of water resources including natural and social respects, the composed system is very complex, large, including a number of factors, which influence and role each other, there is also active and reactive. Therefore, the definition of water resources carrying capacity, there is no unified understanding. Many scholars have put forward their points. Shi Yafeng recognize that water resources carrying capacity is the water resources in certain areas, in certain stages of social history and science and technology development, while not undermining social and ecological systems, the maximum load the capacity of agriculture, industry, city size and population, is a change integrated goal of social, economic, scientific and technological development [10]. Xu You-peng proposed water resources carrying capacity refers to certain technical and economic level and social production conditions, the ability of water resources supply agricultural production, people living and ecological environment protection, which is the largest water resources development capacity, in this capacity, water can be updated and natural circulation, continue to be utilized by people and benefit mankind, without causing environmental degradation [11]. Chen yangbo define water resources carrying capacity is "a certain area of water resources, to meet the conditions for the water resources sustainable use, can support the scale of social and economic - population - environmental development [12]"

Regional water resources carrying capacity evaluation index system

1. Evaluation index system construction
Yang Guang (2009) use water resources in arid areas and utilization characteristics establish water carrying capacity evaluation indicator system, such as the per capita amount of water resources, water resources utilization rate, vegetation coverage, sewage treatment rate, ecological environment water rate, natural population growth, urban rate, per capita GDP, proportion of tertiary industry in GDP, per capita share of grain, water-use efficiency and other 11 indicators [5]. Chen Nanxiang (2010) refer to the national indicator system of water supply and demand balance analysis, based on socio-economic development of Yuzhou and water utilization, ultimately select 8 indicators as water resources carrying capacity indicators evaluation index, such as the amount of water per capita, per capita water supply, water use efficiency, water demand modulus, fixed domestic water, industrial yuan output value of water, farmland irrigation rate, ecological environment water rate [13].

2. Index system evaluation criteria
Index system evaluation criteria are an important part of water resources carrying capacity evaluation, directly affect the objectivity and accuracy of the evaluation results. At present, index system evaluation criteria is few studied, such as Yang Guang (2009) gives three evaluation criteria for its 11

indicators index system [5]. Chen Nanxiang (2010) for its 8 indicators divided into three evaluation levels [13].

Based on the existing research results, combine the social and economic development level and characteristics of water resources carrying capacity assessment, regional water resources carrying capacity is divided into five levels: good, better, normal, poorer and poor.

Considering the indicators average, the upper limit and lower limit values of China in recent years, as well as some related indicators alert the international community, according to five levels, identified 20 evaluation indicators of the evaluation criteria, such as GDP per capita and GDP growth rate, reference the analysis of economic development nearly 10 years and regional economic development level, comprehensive identified 5 evaluation criteria, urbanization rate based on the overall development plan of different cities determine evaluation criteria, per capita water resources, per capita water supply and water resources utilization are analyzed according to various regions of our country as well as water resources development and utilization of water supply, identify 5 evaluation criteria. Other index system is a comprehensive analysis to determine the socio-economic development in accordance with relevant information and research results has a certain reference value.

Water resources carrying capacity evaluation index criteria are in Table 1.

Table 1. Water resources carrying capacity evaluation index criteria

Evaluation index	Poor	Poorer	Normal	better	Good
Per capita GDP (million)	<1.0	1.0-1.5	1.5-2.0	2.0-2.5	>2.5
GDP growth (%)	<8.5	8.5-9.0	9.0-9.5	9.5-10.0	>10.0
Comprehensive yuan GDP water consumption (m^3)	>600	300-600	100-300	50-100	<50
Industrial output proportion of GDP (%)	<30	30-40	40-50	50-60	>60
Population density (people / km^2)	>800	700-800	600-700	500-600	<500
Natural population growth rate (‰)	>7	5-7	3-5	1-3	<1
Urbanization rate (%)	<35	35-40	40-45	45-50	>50
Water demand modulus (ten thousand m^3/km^2)	>80	60-80	45-60	30-45	<30
Eco-environmental water rates (%)	<2	2-3	3-4	4-5	>5
Forest coverage (%)	<9	9-12	12-15	15-18	>18
Soil erosion rate (%)	>25	20-25	15-20	12-15	<12
River and lake water rates (%)	<6	6-9	9-12	12-15	>15
Water Environmental Capacity	Assimilative capacity is far less than the amount of pollutants	Assimilative capacity of slightly less than the amount of pollutants	Assimilative capacity is equal to the amount of pollutants	Assimilative capacity is slightly larger than the amount of pollutants	Assimilative capacity is much larger than the amount of pollutants
Surface water quality	Compliance rate of water functional areas <60%	Compliance rate of water functional areas 60%-70%	Compliance rate of water functional areas 70%-80%	Compliance rate of water functional areas 80%-90%	Compliance rate of water functional areas >90%
Ground water quality	V	IV	III	II	I
Sewage treatment rate (%)	<35	35-50	50-65	65-80	>80
Per capita water resources （m^3/people）	<1700	1700-2200	2200-2500	2500-3000	>3000
Per capita water supply （m^3/people）	<250	250-300	300-350	350-400	>400
Utilization of water resources (%)	>80	65-80	45-65	30-45	<30
Water modulus （ten thousand m^3/km^2）	>80	60-80	45-60	30-45	<30

Set pair analysis assessment model

1. Principles of set pair analysis evaluation model

Set pair analysis is a systematic analysis of handling the uncertainty problem, the core idea is contact objective things and uncertainties of being studied deterministic as a system analysis and processing. So-called set means two sets which have some contact pairs consist, principle of set means in a certain context, analysis the identity, difference, opposition of two pair sets (A, B) features. Uncertainty relation of set described by contact degree, which is

$$m_{A-B} = \frac{S}{N} + \frac{F}{N}i + \frac{P}{N}j \qquad (1)$$

Where: N is the total number of the sets; S is the number of identical; P is the number of oppositional; F is the number of differences; i is uncertainty factor, depending on difference circumstances take the value of the range $(1, 1)$, sometimes only play the role of differentially labeled; j is opposed coefficients, in the calculation, sometimes only play the role of marked antagonistic. Usually make a = S / N, known as same degree, b = F / N is called difference degree, c = P / N is called opposition degree. By the definition, a, b, c satisfy the normalization condition a + b + c = 1, so the formula (1) can be written as

$$m_{A-B} = a + bi + cj \qquad (2)$$

Formula (1) and (2) is commonly used several contact. Usually take bi of $m_{A-B} = a + bi + cj$ expands to $bi = b_1 i_1 + b_2 i_2 + ... + b_k i_k$, then obtain the hierarchy mathematical formula, such as k = 3, can get a five-membered contact degree expressions.

$$m_{A-B} = a + b_1 i_1 + b_2 i_2 + b_3 i_3 + cj \qquad (3)$$

Where: a, b_1, b_2, b_3, c called the contact component, which meet the normalization condition; i_1, i_2, i_3, j called the contact component coefficient, i_1, i_2, i_3 the real difference is the component form of uncertainty factor i. Value i_1, i_2, i_3, j, get the value of contact degree called five-membered contact number.

For a specific question, when the set is composed, contact components can be directly calculated, usually take $j = -1$, so the central question is to determine i_1, i_2 and i_3. When they determined, the value of the contact degree of the problem is determined.

2. Method of contact component coefficients' value

When data and standard are given, the contact component a, b_1, b_2, b_3, c in SPA is a certain problem, while the contact component coefficient i_1, i_2, i_3 is uncertain. In this paper, select the coefficient of contact component a is 1 in formula (3), that compare with the assessment and classification criteria index is in five contact component; b_1 means the comparison of the sample value comparison and evaluation classification criteria, is in four linked components, its coefficient i_1, i_2, b_2 and b_3, i_3 and so on.

Case studies

Gaochun District located in the southwest of Jiangsu Province, locate at latitude 31 ° 13 '~ 31 ° 26', longitude 118 ° 41 '~ 119 ° 12', Lishui is in the north, Liyang is in the east, southern and western Anhui langxi, XuanZhou, Dangtu three counties (cities), have 8 town, 1 district and 163 administrative villages. North-south distance is 29km, the biggest distance of East-west apart 49km, with a total area 801.8km^2, which land area 566.5km^2, accounting for 70.65%, water area 235.3km^2,

accounting for 29.35%. Gaochun area bounded by the gate of Maodong, belonging to Shuiyang River and Taihu two river systems. Territory west Shuiyang River wear through, in the middle Xu River, Guanxi River east to west, north and south communicate paint Bridge River, combined with Yunliang River, Hengxi River, Gangkou River, Shishu River, Zhuanqiang River, Shigu River, Yaxi River, totally 17 key rivers. And have 192 general rivers, 16 reservoirs, 21423 embankments. Gaochun district by district water resources can be divided into four, namely Guheng Lake West, Longdun River Reservoir, Gucheng Lake East and Taihu Lake West.

According to the basic situation of water resources Gaochun area, select 2012 as a representative year, calculate the corresponding evaluation. Taking into account Gaochun area belongs southern region, soil erosion is not obvious, so do not consider soil erosion rate index in actual evaluation. The indicators are shown in Table 2:

Table 2. Value of water evaluation index, Gaochun district, Nanjing

Index	Index value	Index	Index value	Index	Index value
Per capita GDP (ten thousand yuan / people)	4.03	Water demand modulus（ten thousand m³/km²）	98.12	Sewage treatment rate （%）	53
GDP growth （%）	13	Eco-environmental water rates （%）	8.25	Per capita water resources （m³/people）	6245.94
Ten thousand yuan integrated Water consumption （m³）	200	Forest coverage rate （%）	26	Per capita water supply （m³/people）	1021.71
Industrial output proportion of GDP (%)	55	River and lake water rates （%）	29.35	Utilization of water resources （%）	45.4
Population density（people /km²）	531	Water environmental capacity	Normal	Water modulus（ten thousand m³/km²）	76.76
Natural population growth rate （%）	2.48	Surface water quality	Normal		
Urbanization rate （%）	69	Ground water quality	Normal		

Set provided evaluation C = {C1, C2, C3, C4, C5}, where C1 = {1 / Fine}, C2 = {2 / Good}, C3 = {3 / Normal}, C4 = {4 / Poor}, C5 = {5 / Bad}.

Determine the relative weight of the heavy layers index system, the right weight of social economic systems, environmental systems and water systems are (0.5472, 0.1897, 0.2631). Using the steps of set pair analysis, calculate level index comprehensive evaluation of five element connection number as shown in Table 3:

Table 3. Level index comprehensive evaluation of five-membered contact number, contact master number and rating scale principal value

Number	One index	Comprehensive evaluation five-membered contact number	Contact master value
1	Socio-economic system	$m_1 = 0.4677 + 0.2912 i_1 + 0.0936 i_2 + 0.1475 j$	$m_1 = 0.4658$
2	Ecological environment system	$m_2 = 0.3374 + 0.2375 i_1 + 0.3433 i_2 + 0.0818 j$	$m_2 = 0.3743$
3	Water system	$m_3 = 0.7658 + 0.1191 i_1 + 0.0588 i_2 + 0.0564 i_3$	$m_3 = 0.7972$

Calculate and determine the five-element connection number of the total index comprehensive evaluation:

$$m = 0.5214 + 0.2357 i_1 + 0.1318 i_2 + 0.0148 i_2 + 0.0962 j \qquad (4)$$

According to "sharing principle", five-element connection number value should be located in the interval [-1,1] in four equal points, so make $i_1 = 0.5$, $i_2 = 0$, $i_3 = -0.5$, $j = -1$ to get each one main evaluation index value I_m (1≤m≤3) ,which comprehensive assessment contact number of master values (see Table 3) and the total index, $m = 0.5356$.

According to "sharing principle", determine the scope of the five-element connection number to five principal value of the interval [0.6, 1], [0.2, 0.6], [- 0.2,0.2], [- 0.6, -0.2], [- 1, - 0.6], respectively

response C1 = {1 / Fine}, C2 = {2 / Good}, C3 = {3 / Normal}, C4 = {4 / Poor}, C5 = {5 / Bad}levels, can be seen Gaochun water resources carrying capacity is 2 / good.

Proposals and measures

Gaochun water resources development and utilization rate is not high, although the transit of water is very rich, but due to limitations of water supply capacity cannot meet the demand of water resources to provide social and economic development. In addition to the status quo in wet years, the water supply capacity and cannot meet the needs of the county's water, water carrying capacity potential uneven distribution, Gucheng Lake Western water resources carrying potential capacity is much higher than the other three partitions. With the social and economic development and people's living standards improve, increasing demand for water in industrial and agricultural production and daily life, the need to increase water conservation efforts to mitigate the potential carrying capacity of water resources decline. Gaochun in terms of workers and peasants and other industrial and ecological water allocation is not reasonable, affecting the water carrying capacity.

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