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Evaluation of Water Environmental Carrying Capacity in Huaihe River Basin

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Abstract: Based on the theory of water environmental carrying capacity, Through the establishment of evaluation index system of water environmental carrying capacity and the application of vector norm method, the water environmental capacity level is evaluated in Huaihe River Basin and analyzed change trend of water environmental carrying capacity index. The results indicated that Huaihe River Basin water environment carrying capacity has tendency of increasing in 2004-2015, its water environment carrying capacity was varied from 0.01 to 0.06, but the water environmental carrying capacity is low. Research results can provide scientific theory and technical support for regions of Huaihe River Basin works out scientific measure to improve the water environment carrying capacity, so as to realize sustainable development strategy

Keywords: *evaluation index system, water environmental carrying capacity (WECC), vector norm method, Huaihe River Basin.*

1. Introduction

Water is an important part of the ecological system, and it is one of the indispensable conditions for human survival and development. Water environmental carrying capacity (WECC) is the ability that in a certain period a water environment system can maintain of a region's economic-social development. The capacity of high and low is directly related to the whole ecological environment system of security and the sustainable development of human society. With the development of society and economy, pollution problem is increasingly prominent and seriously affected the WECC, so it has caused the wide attention of the society. At present, the research on the bearing capacity of water environment is less, and most of it is in the category of sustainable development [1-5]. For sustainable development, it is more and more urgent to research water environment carrying capacity. Since the 1990s, the domestic research on WECC had just beginning. Then many experts and scholars from different angles to put forward the related concepts, research methods, and the evaluation index system and calculation model. However, the studies of WECC to judge whether the water environment is coordinated with social economy, have been put forward.

In this paper, on the basis of summarizing the existing research results and the connotation of WECC, the author scientifically evaluated the level and researched trend of WECC of Huaihe River Basin. For the establishment of scientific development strategy in the region, coordinating the relationship between the economic-social development and water environment protection, inhibiting water environmental pollution, the Huaihe River Basin sustainable development, the paper is of important theoretical value and guiding significance.

2. Research overview

Huaihe River Basin is located in the eastern part of China, between the Yangtze River and Yellow River basin. The area of Huaihe River Basin is 270000 square kilometer, across five provinces and 40 cities. At present, the economic-social of Huaihe River Basin develop rapidly, and its GDP is 3.45 trillion Yuan, accounting for 8.6% of national GDP; Huaihe River Basin is important agricultural products base in China and occupies an important position in the economic-social development. However, per capita and per acre of water resources is only 1/5 of the national average, so it is a serious water shortage area in China; At the same time, along with the fast development of economy and society in Huaihe River Basin, water pollution incident come up frequently so that more than 50% of the water of Huaihe River Basin is exceed standard. Then, water shortage and pollution problem have become the main restriction factor of regional economic-social sustainable development.

3. Construction of evaluation index system

WECC is closely related to regional economic-social development and sustainable development. Scientific, reasonable and feasible comprehensive evaluation index system of regional WECC is the basis to develop and manage.

3.1. Design guidelines of the indexes

Regional water environment carrying capacity is influenced by the regional economic-social development, water resource endowment and water ecological environment conditions, which is the result

of mutual restriction and mutual coupling of such factors. Therefore, the establishment of the comprehensive evaluation index system of WECC should be constructed from different aspects and angles. Follow the guidelines below.

1) Function orientation

Categorizing comprehensive evaluation index and selecting different index variables based on the environment, natural attribute, social attribute and resources attribute.

2) Social conditioning

The economic-social development will inevitably be effect to environment. But the water environment improved with the progress of science and technology. Thus, when building a comprehensive evaluation index, it should be considered the progress of science and technology.

3.2. Indexes design principles

1) Strong Policy relevance: the selected indexes should meet protection policy of Huaihe River Basin the principles to realize the coordinated development of the economic society and resources environment.
2) Strong practicability: the selected indexes should be concise and easy to understand, basis on scientific theory, and accepted easily by the public. At the same time, the establishment of the index system should associate with evaluation model to facilitate application.
3) High information integration: the number of the selected indexes should be simple, but the information it contains should be highly integrated, can reflect the economic-social development comprehensively and the relationship between the water environmental system and change in temporal and spatial scales.
4) Data is easy to obtain: the selected indexes of quantitative data should be accessible to ensure operability.

3.3. The index system framework

Water environment is an important part of the ecological environment, so WECC is not only associated with structure and function of water resources system, but with the pressure and the degree by human in economic-social activities. That is to say, strengthening management and investment in science and technology can improve WECC and develop harmoniously. According to above analysis, the author constructed the evaluation index system of WECC of Huaihe River Basin by tertiary system framework---evaluation index value, the evaluation index, index variable. (Table 1)

Table 1: *Huaihe River Basin water environment carrying capacity evaluation index system frame*

Names of Indexes	Main Points
index variable	At the foot of the evaluation index system; Concise, simple numerical, high information integration, the variable data accessible.
evaluation index	Evaluation index reflect the overall characteristics of indicator variable; It is divided into different categories, and types of variables can be further divided into different indexes.
evaluation value	In the whole evaluation value measure WECC level and it is at the top of index system.

According to the index system framework, the author builds the concrete evaluation index system of WECC of Huaihe River Basin. In view of the special water environment and the availability of core data, when selecting the evaluation indexes, the author mainly considered and adopted indicator variables directly related to the water quality and water ecological environment. (Table 2)

Table 2: *Huaihe River Basin water environment carrying capacity evaluation index system*

Index Type	Index Variable	Code	Definition of Index	Weight
economic-social development level	Per Capita GDP(Yuan)	X1	the economic level (+)	0.121
	Water consumption per 10,000 Yuan of value-added by industry(cubic meter)	X2	water efficiency in regional economic development(-)	0.081
	living water consumption per day(L)	X3	Regional water pressure of people's life(-)	0.037
	urbanization level(%)	X4	pressure of urban development to water resources (-)	0.034
	irrigation water consumption per acre(cubic meter)	X5	pressure of agricultural development to water resources (-)	0.031
water resources endowment	total water resources(a hundred million cubic meter)	X6	water supply capacity(+)	0.083
	the rate of the surface water resource	X7	supporting capacity of surface	0.084

	use(%)		water(-)	
	shallow groundwater exploitation rate(%)	X8	supporting capacity of groundwater(-)	0.050
	the water diversion scale(one hundred million cubic meter)	X9	outer regional water supply capacity(+)	0.072
Water resources and eco-environment	quantity of wastewater effluent(one hundred million ton)	X10	Regional water pollution condition(-)	0.043
	COD emissions Per ten thousand yuan of GDP(kg)	X11	Regional water resources utilization efficiency and quality(-)	0.141
	Ammonia nitrogen emissions Per ten thousand yuan of GDP(kg)	X12	Regional water resources utilization efficiency and quality(-)	0.166
	Reservoir water qualification rate all year round(%)	X13	the reservoir water quality(+)	0.021
	Rate of water quality above Ⅲ all year round(%)	X14	regional ecological quality of river water(+)	0.037

i.e. (+) showed it was effect, the parameter values, the better; (-) represented negative effects, the parameter values as small as possible.

1) The economic-social development level. It reflects the pressure brought by Huaihe River Basin on the economic-social development in different periods, which are closely related to structure, population and other factors of the economic-social development in Huaihe River Basin. The changes of index variable values will simulate positive or negative effects on the level of WECC.
2) Water resources endowment. It reflects the water resources endowment status utilization degree and level of Huaihe River Basin. Changes of index variable values indicate the size of the intensity that can withstand by development and utilization.
3) Water resources and eco-environment .It reflects sewage education measurement, pollution control and governance effect of Huaihe River Basin. And it is the prediction of supporting capacity of water and land resources.

4. Evaluation method of WECC of Huaihe River Basin

As the deterioration of ecological environment and environmental pollution, people pay more and more attention to environmental issues which become hot issue in China.

4.1. Research summary of WECC

At present, the main methods of WECC include the fuzzy comprehensive evaluation method, principal component analysis, system dynamic method, trend of conventional method and the multi-objective decision method and so forth. On the basis of evaluation index system of water environmental capacity Fuzzy comprehensive evaluation is the method that could fix the weight of each evaluation index and make comprehensive evaluation Factors affecting the bearing capacity of water environment through comprehensive evaluation matrix. Principal components analysis method is a statistic method which uses reducing dimensions thought to integrate many combinations of indexes into fewer indexes. The main ingredient analysis, which can solve the traditional analysis problems effectively, is a kind of statistical analysis containing multiple attribute decision-making. Numerical Simulation is widely used in dynamic systems. Based on the system dynamics principle, system dynamic simulation in system dynamics theory can used for exploring quantitatively with high order, nonlinear and multiple feedback and complex time-varying system; Regular trend method focused on statistical analysis and select the relevant evaluation index to reflect the current state of the regional water environment carrying capacity; Multi-objective decision listed in the main constraints on object to seek the optimal solution of multiple target . It is presented that WECC in future would be studied using more modern techniques and methods, focusing on special regions and combining multidisciplinary methods [6-10].

However, there are subjective problems and information lost existing in the application of fuzzy synthetic evaluation method; Principal component analysis can overcome the subjectivity of fuzzy comprehensive evaluation, but it is only suitable for exploiting a given year; System dynamics is applicable to deal with high order, nonlinear problem, not suitable for research long-term development; Trend of conventional is difficult to deal with complex system interaction and coupling relationship between indexes. Multi-objective decision factors are too subjective and the authenticity of the evaluation results is distorted.

The evaluation methods above have advantages, but there are also disadvantages. Due to the laws of changes and developments, impacts of WECC on economic-social development are various and long process.

4.2. Vector analysis method

Vector analysis method is often used to compare WECC in horizontal (different areas at the same time) and vertical (in the same area at different times). Suppose there are m level years and m evaluation values of WECC, and evaluation values are (j =1,2,…, m) E_j.Than set Each vector(evaluation value) set includes n component, that is

$$E_j=(E_{1j},E_{2j},...,E_{nj}) \quad (1)$$

Normalize indexes:

$$\overline{E}_j=(\overline{E}_{1j},\overline{E}_{2j},...,\overline{E}_{nj}) \quad (2)$$

For positive effect index, the method of standardization was linear:

$$\overline{E}_{ij}=E_{ij}/\sum_{i=1}^{n}E_{ij} \quad (3)$$

For negative effects, firstly take the reciprocal E'_{ij}, and use the linear standardized method for processing:

$$\overline{E}_{ij}=E'_{ij}/\sum_{i=1}^{n}E'_{ij} \quad (4)$$

So, the jth evolution value of WECC is the normalized vector module. That is,

$$\left|\overline{E}_j\right|=\left[\sum_{i=1}^{n}(W_{ij}\overline{E}_{ij})^2\right]^{1/2} \quad (5)$$

W_{ij} --- Weight of the i th index of the j th WECC value;

WECC evaluation value calculate by vector modulus method are between 0-1.

4.3. Confirm weight of evaluation index

At present, the method to confirm the weight of evaluation index system is a lot. However, in this paper, the variation coefficient method is used to objectively determine the weight of evaluation index to avoid subjective influence.

Basic thought of the method is that in the multi-index comprehensive evaluation, if variation of an index is larger, which is able to clearly distinguish the evaluation objects in the level, and then the index should be given greater weight. v.v.

Calculation procedure is as follows. First, calculate the coefficient of variation

$$V_i=\frac{\sigma_i}{\overline{x}_i} \quad (i=1,2,...,n) \quad (6)$$

V_i --- coefficient of variation of the i th index;

σ_i --- Standard deviation of the i th index;

$\overline{x}_i$ ---Mean of the i th index.

Weight W_i of indexes should be got by normalizing the coefficient of variation.

$$W_i=\frac{V_i}{\sum_{i=1}^{n}V_i} \quad (7)$$

According to a formula (6) (7) and table 3, the author obtain all of the weights.(Table 2)

5. Evaluation and analysis

5.1. The data source and the evaluation result

According to the Huaihe River Basin water resources bulletin, China statistical yearbook in 2004-2015 and evaluation index system described in the paper, The value of WECC of Huaihe River Basin could be obtained. (Table 3)

Table 3: *The value of Huaihe River Basin Water Environmental Carrying Capacity Evaluation in 2004 —2015*

Node	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
X1	5248.77	5647.68	7100	8100	9500	11300	13300	16000	18800	22600	25500	29700
X2	134	94	174.00	151	186.1	162.3	143.2	126.74	96.48	69.59	62.49	48.9
X3	122.95	119	126.90	128.15	92.45	85.7	85.2	86.1	90.49	90.4	91.37	90.13
X4	27.26	29.87	31.04	32.55	34.26	35.69	37.67	39.04	40.72	42.08	43.22	45.67
X5	176.58	275	324.40	297	216.8	270.9	262.5	274.47	251.06	269.11	285.85	290.21
X6	514.70	1164.66	482.96	656.58	1695	653.2	1265.89	882.4	1198.87	905.34	710.92	859.59
X7	82.10	30.70	75.40	71.6	17.8	66.9	32.2	51.7	33.30	49.90	71.4	54.6
X8	44.30	38.30	43.80	43.1	23.8	38.7	51.7	58.1	58	63.7	46.4	44.2
X9	87.87	83.75	108.69	101.99	43.28	50.4	50.27	56.35	37.36	60.54	75.18	81.9
X10	45.93	48.69	56	59.82	74.09	65.75	70.45	72.5	78.09	79	85.57	89.73
X11	6.66	5.88	4.69	5.11	4.58	2.92	2.81	1.99	1.44	0.88	0.81	0.63
X12	1.02	0.84	0.64	0.56	0.47	0.29	0.30	0.23	0.16	0.11	0.09	0.08
X13	79.11	85.71	80.95	90.48	69.7	78.13	84.38	62.5	72.97	83.78	81.08	80.49
X14	21.6	24.40	30.1	33.7	28.8	33.5	32	37.2	37.7	38.4	37.9	38.8

According to formulas and tables above, calculation results of Huaihe River Basin water environment capacity in 2004-2015 is obtained by calculating.

Table 4: *Calculation results of Huaihe River Basin water environment capacity in 2004-2015*

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Evaluation Value	0.0151	0.0200	0.0162	0.0168	0.0263	0.0192	0.0228	0.0241	0.0314	0.0419	0.0476	0.0565

Meanwhile, we can get the change trend of Huaihe River Basin water environmental capacity in 2004-2015 is as follows. (Figure 1)

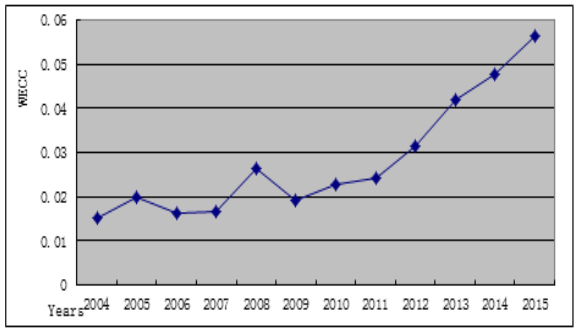

Figure 4: *Change trend of Huaihe River Basin water environmental capacity in 2004-2015*

5.2. Analyses of evaluation result

1) In 2004-2015, WECC level was growing at an annual speed of 15.2%, the total level of which is comparatively low. The minimum and maximum of WECC is 0.0151 in 1999 and 0.0565 in 2010 both which have not reached level of 0.1. This is mainly because of the fast enhancement of urbanization, the rise of sewage discharge in economic-social development. There exists a long-term overweight problem though COD and ammonia emissions are reduced constantly. However, there is still exceeding standard for a long time, coupled with less Ⅲ class water. For a long time, human irrational utilization of water is destroying water environment so as to deterioration of water quality. So the overall level of WECC of Huaihe River Basin should for long-term maintain a low level.
2) In 2008, there was a twist of change of WECC of Huaihe River Basin, for world, is divided into 2004-2007 years of slow growth period and 2008-2015 of fast growth period. In 2004-2007, there was a steady growth of value of WECC caused by great change of irrigation water consumption per acre, total water resources, water qualification rate. However, from 2008 to 2015, there was a fast growth of value of WECC caused by rapid increase of irrigation water consumption per acre, total water resources, water qualification rate. Meanwhile, water consumption per 10,000 Yuan of value-added by industry, utilization ratio of surface water, rate of shallow groundwater exploitation, COD and ammonia emissions had reduced gradually year by year, so the value of WECC grow rapidly.
3) The result that the overall level of WECC of Huaihe River Basin is low is in conformity with the actual situation of Huaihe River Basin. Huaihe River Basin is across central and eastern regions, and there is still a large gap between economic-social developments of these provinces. In addition to the relatively high level of development of Jiangsu province, other four provinces in the basin is in the early stages of industrial development, economic-social development level, facing the huge pressure of developing economy. To the rapid development of the region's economic-social, a big problem of wastewater treatment comes up. And because of the lack of control measures and water quality worsen sharply; Transregional water pollution is very serious. As a serious shortage of Huaihe River Basin water resources and mismatch between supply and demand, the level of WECC of Huaihe River Basin is not high. This has an adverse effect on current economic-social development.

6. Conclusion

In this paper, starting from the connotation of water environment bearing capacity theory, combined with the actual situation of Huaihe River Basin water environment, the evaluation index system of Huaihe River basin water environment carrying capacity was constructed .Then variable modulus method was adopted to evaluate the water environment bearing capacity level of the Huaihe River Basin and its spatial change laws in 1999-2010. From 2004 to 2015, WECC level was growing at an annual speed of 15.2%, the total level of which is comparatively low that is in conformity with the actual situation of Huaihe River Basin. There should be strictly made corresponding measures to solve the problem of Huaihe River Basin water pollution of the environment, enhance the capacity of the Huaihe River Basin water resources, and improve the bearing capacity of the Huaihe River Basin water environment, in order to realize sustainable development.

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