Nature Environment and Pollution Technology
An International Quarterly Scientific Journal
p-ISSN: 0972-6268
(Print copies up to 2016)
e-ISSN: 2395-3454
Vol. 19 No. 2 pp. 839-844 2020
Original Research Paper
https://doi.org/10.46488/NEPT.2020.v19i02.042
Open Access Journal

Water Environment Carrying Capacity Evaluation by Cloud Theory in Beijing

Men Baohui† and Lina Tuoku
North China Electric Power University, Renewable Energy Institute, Beijing 102206, China
†Corresponding author: Men Baohui; menbh@ncepu.edu.cn

Nat. Env. & Poll. Tech.
Website: www.neptjournal.com

Received: 10-07-2019
Accepted: 19-09-2019

Key Words:
Water environment;
Carrying capacity;
Comprehensive evaluation;
Cloud theory

ABSTRACT

With human social and economic development, the problem of consumption and pollution of water resources greatly reduces the quality of human life. The research on the carrying capacity of the water environment can provide a theoretical basis and data support for coordinating the contradiction between man and nature and the green development of the urban economy. The driving force-pressure-state-response model evaluation index system, combined with entropy method to strike the index weight, using cloud theory calculated the level of 2004-2017 for each year of the Beijing water environmental carrying capacity. The results show that the water environment carrying capacity of Beijing has been rising in the past 14 years. It is the lowest in 2004 and tends to be stable after reaching a higher level in 2010. Despite Beijing's water environment carrying capacity has increased, but overall still in the overload state.

INTRODUCTION

Water resources interact with human life, and the quality of the water environment sustains the survival and development of mankind. With the development of human society and economy and the continuous expansion of population, the contradiction between human beings and nature has become increasingly prominent. The issue of resource and environmental carrying capacity has become an important indicator to measure the quality of development of a certain country or region and widely received by the people of the world (Wang & Li 2018). The water environment is an important environment in which humans depend. People's research on water environment carrying capacity (WECC) has been very long, although many researches have been made, there is still no consensus on the concept. However, in the existing content of the WECC, the actual content still has many similarities (Qu et al. 2017). In essence, even if the definition of WECC is different in different fields, it is a statement of the relationship between water environment and economic development and human activities. From a macro perspective, the WECC refers to the basic ability to support human production, life and social and economic development under specific preconditions. Microscopically, it refers to the ability of the water environment to effectively degrade pollutants and realize effective energy cycle based on ensuring its normality. Regardless of the type of research, we find that the water environment changes with the evolution of human society, and the actual carrying capacity has certain limits. Once this limit is exceeded, the water environment will be greatly affected, which in turn affects the normal production and life of human beings (Zhang 2018).

With the deepening of research, domestic and foreign scholars have used different methods to study the environmental carrying capacity and achieved a lot of results. Based on the analysis of Beijing wetland water resources system, Wang et al. (2017) evaluated the carrying capacity of water resources through the system dynamics model and put forward suggestions on the optimization of urban wetland management policies. Wang et al. (2018) took Zhengzhou city as the research object, used entropy weight method to allocate the weight of corresponding indexes from 2007 to 2016, and used TOPSIS model to evaluate the carrying capacity of water resources. Huang et al. (2017) took 4 subsystems coupling as the basic framework, selected 12 indicators to construct the water environment carrying capacity model, and improved the traditional catastrophe theory by using the refinement method of the ranking table to obtain the adjusted comprehensive value. Then, according to the evaluation habit, the fuzzy evaluation method is selected to determine the evaluation threshold, and the five-level evaluation method is adopted to evaluate the water environment carrying capacity, and finally, the water environment carrying capacity of Yichang City is evaluated. Zhang et al. (2015) established a comprehensive evaluation index system and compared the carrying capacity of resources and environment from 2005 to 2012 from land, water resources, transportation and the environment. Song (2016) analysed the land, water, biological environment and air pollution in the Pearl River

Delta region of China to understand the pollution situation in the region, and analysed the sustainable development of tourism resources. Based on environmental carrying capacity, they discussed the interaction mechanism between the external environment (natural, economic, social) and internal environment (tourism subject and object). Wang (2016) took Xihe River basin as the research object, constructed an index system based on Water-Ecology-Socio-Economic system, and established a System Dynamics (SD) model to deduce the carrying capacity of water resources under different circumstances, and then analysed methods to improve the carrying capacity of water resources in this basin. It can be seen that the research method of environmental carrying capacity provides better guidance for the research and practice of environmental carrying capacity improvement in different regions.

In this paper, based on the index system of comprehensive evaluation method to build the corresponding evaluation system, with Beijing as the object of evaluation, combining the entropy weight method was carried out on the related data in 2004-2017 index weight distribution, based on the cloud theory is adopted to improve the corresponding bearing capacity evaluation, to coordinate the development of social economy and the connection between the natural environment to provide the reference.

MATERIALS AND METHODS

Establishment of Evaluation Index System

The water environment not only provides the necessary material foundation for social and economic development and the ecology but also is the place which bears the pollution. To ensure the scientificity and applicability of policy suggestions, as well as the accuracy and rationality of evaluation results, it is necessary to build a reasonable and complete index system, which is also the basis of quantitative evaluation of WECC (Wang & Li 2018). Economic development and social demand will have a driving force on the water environment and human activities on water environment pressure, the driving force and pressure change the state of the water environment, according to the situation of environment and society to respond, to ease the economic, social, and human activities on water environment pressure, maintain the health and stability of the system status of water environment (Wang 2016). The above logic relations can be well reflected by the Driving Force-Pressure-State-Response evaluation model. The selection of each indicator should be based on the actual situation of the research area and should be representative and take into account the difficulty of obtaining and processing index data. Based on the above considerations, the evaluation index system of Beijing's water environment carrying capacity adopted in this paper is shown in Table 1.

According to the real situation of each index and referring to the average level of each index at home and abroad, the evaluation criteria are divided into five classes. Class I represents the extremely weak carrying capacity and serious water resources overload under this state. Class Ⅱ represents the relatively weak carrying capacity under this state, with slight water resources overload. Class III represents the matching of carrying capacity under this state with economic development. Class IV represents the state of bearing capacity is strong, has great potential for development and utilization of. Class V represents the extremely strong carrying capacity under this condition, and has great potential for development and utilization. The specific classification criteria are shown in Table 2.

Table 1: Beijing WECC evaluation index system.

Target layer	Rule layer	Index layer	Serial number	Unit	Property
Water environment capacity	Driving Force	GDP per capita	A_1	10,000 Yuan /person	+
		Urbanization rate	A_2	%	+
		Permanent population density	A_3	People/km²	-
	Pressure	Ratio of effective irrigated area to sown area	B_1	%	+
		Per capita daily domestic water consumption	B_2	L/(person·y）	-
		Forest coverage	B_3	%	+
	State	Water resources per capita	C_1	m³/person	+
		Fertilizer application per unit area	C_2	kg/hm²	-
		Chemical aerobic discharge	C_3	10,000t	-
	Response	Percentage of Sewage Disposed	D_1	%	+
		Water consumption per ten thousand Yuan GDP	D_2	m³	-
		Ecological water use rate	D_3	%	+

Survey of Research Area

Influenced by geographical and climatic conditions, the rainfall in Beijing is not evenly distributed in time and space within the year, and the per capita water resource at the end of 2017 is only 137 m^3, which is a typical mega-city with severe water resource shortage. With the rapid development of society and economy, the per capita GDP of Beijing has been increasing rapidly in recent years, and the consequent demand for water has also increased sharply. Therefore, the water resource problem is extremely urgent.

Data Information

This paper evaluated the WECC of Beijing from 2004 to 2017, and the required data come from the national bureau of statistics, Beijing water resources bulletin, Beijing statistical yearbook and other data. Through simple calculation, the final values of each indicator are shown in Fig. 1 (A_3, B_2, C_1 and C_2 data are based on the right vertical axis, while the other indicators are based on the left vertical axis). Among them, the statistical calibre and accounting method of chemical oxygen demand (COD) emission index has been adjusted since 2011.

Cloud Theory

When evaluating the bearing capacity of water environment, we can use words like strong bearing capacity, general, weak overload and other words with a certain ambiguity. There is no specific value corresponding to them, but the only vague range of value. And the range of values defined by different people is also different. It is highly random and there is no uniform standard. Cloud model (Yuan 2017) can scientifically and effectively deal with the fuzziness and randomness of such language. This method mainly uses the cloud model transformation method to quantitatively represent the qualitative language existing in people's production and life, to strengthen people's quantitative analysis of uncertain things and data operability.

Assuming the U representation domain, represented by precise numerical values, A is a qualitative concept on U, x is a qualitative language value on U. x corresponds to a degree y ($0 \le y \le 1$), is a random number with a stable trend, the distribution of y on U is called the membership cloud, referred to as the cloud, each group (x, y) becomes a cloud drop. The cloud is a map from domain U to the interval [0,1] (Ni 2018).

The cloud uses digital characteristics such as E_x (expectation), E_n (entropy), and H_e (hyper entropy) to represent its concept of uncertainty. The above three numerical features can unify fuzziness and randomness, and form a mapping relationship between qualitative concepts and quantitative values (Shao 2018).

Expectation E_x: is the value of a qualitative concept that determines the centre of gravity of the cloud. The calculation method is:

$$E_x = (B_{\min} + B_{\max})/2 \quad \ldots(1)$$

Where, B_{min} and B_{max} represent the minimum boundary and maximum boundary of an evaluation grade respectively.

Entropy E_n: the measure of the uncertainty of a qualitative concept. Because the boundary value is a kind of fuzzy boundary in the transition state and corresponds to two levels at the same time, that is, the membership degree of the two levels is equal, so there is:

$$\exp\left[-\frac{(B_{\max}-B_{\min})^2}{8E_n^{\,2}}\right] \approx 0.5 \quad E_n = \frac{(B_{\max}-B_{\min})}{2.355} \quad \ldots(2)$$

Table 2: Beijing water environment carrying capacity evaluation grade standard.

Index	Class I	Class II	Class III	Class IV	Class V
A_1	0-1	1-3	3-5	5-7	7-13
A_2	0-60	60-70	70-80	80-90	90-100
A_3	1200-1400	800-1200	500-800	300-500	100-300
B_1	0-20	20-30	30-50	50-80	80-100
B_2	220-240	200-220	180-200	160-180	140-160
B_3	8-30	30-50	50-60	60-70	70-100
C_1	90-500	500-1000	1000-1700	1700-2600	2600-3500
C_2	550-700	490-550	420-490	360-420	0-360
C_3	45-60	30-40	20-30	15-20	0-15
D_1	0-60	60-85	85-90	90-95	95-100
D_2	300-400	250-300	150-250	50-150	10-50
D_3	0-15	15-30	30-45	45-55	55-100

Hyper entropy H_e: It is the fuzzy measure of entropy that determines the thickness of the cloud. The calculation method is:

$$H_e=k \quad \ldots(3)$$

Where, k is constant. It is determined by the fuzzy threshold of the variable itself (Qi & Zhao 2016). In this paper, k=0.1.

The cloud droplets generated by the forward cloud generator based on the digital characteristics of the cloud (E_x, E_n, H_e) are a mapping from qualitative to quantitative. This paper mainly uses forward cloud generator, and the calculation method (Zhang et al. 2017) is:

(1) First create normal random numbers E_{ni}, with E_n as the expectation and H_e^2 as the variance. Secondly, create normal random number x_i, whose expectation is E_x and variance is E_n^2.

(2) Then calculate the corresponding membership value $r_i = e^{-\frac{(x_i-E_x)^2}{2(E_{ni})^2}}$, ($x_i$, r_i) to form any cloud droplet in the number domain.

(3) Repeat the above process until n cloud droplets are generated.

The corresponding membership degree R is calculated by relevant steps of forward cloud generator:

$$R = \begin{pmatrix} r_{11} & r_{12} & \cdots & r_{1m} \\ r_{21} & r_{22} & \cdots & r_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ r_{n1} & r_{n2} & \cdots & r_{nm} \end{pmatrix}$$

Where: n=1, 2, …, 5, m=1, 2, …,12.

The evaluation grade value $P = (p_1, p_1, \cdots, p_n)$ of water resource carrying capacity can be calculated as follows:

$$P = W \times R \quad \ldots(4)$$

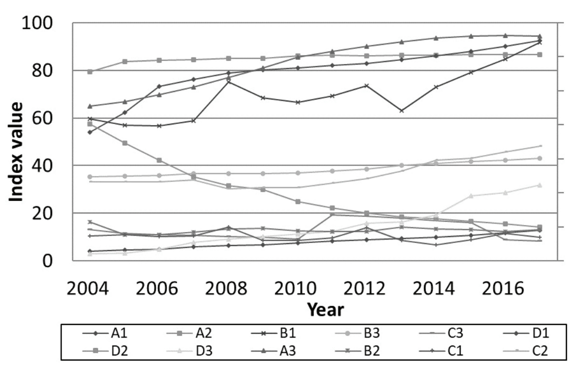

Fig. 1: Original data of each indicator.

Where, W is the weight of each index, which is determined by the entropy weight method in this paper.

Entropy Weight Method

Entropy weight method is a comprehensive and objective method to reflect the characteristics of information contained in index data by using original data. It is widely used in various fields of statistics. In this paper, the entropy weight method is adopted to allocate the weight of evaluation indicators. The specific steps are as follows.

To eliminate the dimension of each index value and unify the variation range of each index value, the following formula is adopted for normalization.

$$\begin{cases} y_{ij}=\frac{x_{ij}-x_{j\min}}{x_{j\max}-x_{j\min}} & \textit{Positive indicators} \\ y_{ij}=\frac{x_{j\max}-x_{ij}}{x_{j\max}-x_{j\min}} & \textit{Negative indicators} \end{cases} \quad \ldots(5)$$

$i = 1,2, \cdots, I.\ j = 1, 2, \cdots, J$

Where, x_{ij} refers to the initial value of the ith indicator to be evaluated in the jth year. y_{ij} refers to the standardized value of the jth year indicator. $x_{j\max}$, $x_{j\min}$ refers to the maximum and minimum value of the (ith) index sequence.

Each evaluation index has a different influence on the evaluation of water environment bearing capacity, so the evaluation index should have different weight. The calculation formula of information entropy w_j is as follows:

$$w_j = \frac{1-e_j}{\sum_{j=1}^{m}(1-e_j)} \quad \ldots(6)$$

Where: $e_j = -\frac{1}{\ln n}\sum_{i=1}^{n} H_{ij} \ln H_{ij},\ H_{ij} = \frac{y_{ij}}{\sum_{i=1}^{n} y_{ij}}$., .

THE ANALYSIS AND RESULTS

To reduce the influence of human subjective factors on the weight distribution, the data in Fig. 1 are firstly normalized by equation (5), and the weights of each index are calculated by equation (6) of the entropy weight method. The final weights are 0.092, 0.030, 0.172, 0.121, 0.037, 0.137, 0.064, 0.057, 0.082, 0.040, 0.049, 0.119. Put this weight into cloud theory, and get the digital characteristics of cloud from equations (1)-(3), as given in Table 3.

According to the corresponding index values, weights and digital features, the forward generator algorithm is used to generate the membership matrix, and then the bearing capacity evaluation results are obtained, as provided in Table 4.

To further analyse the development trend of WECC of Beijing in recent years, the trend chart of water environment carrying capacity for each year from 2004 to 2017 is drawn according to the results in Table 4, as shown in Fig. 2. The year is in the horizontal axis, and the value of water environment carrying capacity is in the vertical axis. According to the principle of entropy weight method and the evaluation grade standard established, the larger the evaluation value of the water environment carrying capacity is, the better the water environment carrying capacity is.

It can be seen from the above results that the carrying capacity of Beijing's water environment has entered a relatively stable state after rapid improvement in the past 14 years. Combining the results of other scholars' research (Qi & Zhao 2016, Liu 2018, Han et al. 2018) on the WECC in Beijing, the results are similar.

It is believed that the carrying capacity of Beijing has been on the rise in the past 14 years, with the lowest carrying capacity in 2004 and stabilizing after reaching a higher level in 2010. From 2004 to 2010, the carrying capacity level of the water environment increased rapidly year by year. This may be due to the low rate of urbanization around 2004. And affected by the technical level, the effective irrigation rate per unit area is not high, COD and sewage treatment rate have room for progress, and the public awareness of environmental protection is not strong enough. But with the development of cities, the industrial structure has changed greatly. The annual industrial output value of Beijing has been growing, while the industrial water consumption has been decreasing. The agricultural industrial structure is gradually adjusting to the direction of water-saving agriculture, which makes the ratio of effective irrigation area to sowing area increase year by year, thus slightly relieving the overload of bearing capacity.

From 2010 to 2014, there was a slight decrease, and the corresponding resident population density continued to increase, which will increase the bearing pressure to some extent. Fundamental changes have taken place in people's forms of water use, such as the rapid development of the food and lodging industry, the popularity of household shower equipment and water appliances, the adjustment of water prices and the equipment of water-saving equipment, etc. On the one hand, the pressure will be alleviated, which can be reflected by the fluctuation of per capita daily water consumption. Since 2011, the statistical calibre and accounting method of chemical oxygen demand (COD) emission index have been adjusted, so the chemical oxygen demand emissions around 2010 have obvious fluctuations, which will inevitably have a greater impact on the evaluation results, which may lead to the highest level of water environment carrying capacity in 2010, and the decline after 2010.

Table 3: Digital characteristics of clouds.

Index	A_1	A_2	A_3	B_1	B_2	B_3	C_1	C_2	C_3	D_1	D_2	D_3
	5	30	1300	10	230	19	295	625	50	30	375	7.5
	2	65	1000	25	210	40	750	520	35	72.5	300	22.5
E_x	4	75	650	40	190	55	1350	455	25	87.5	200	37.5
	6	85	400	65	170	65	2150	390	17.5	92.5	100	50
	10	95	200	90	150	85	3050	180	7.5	97.5	30	77.5
	0.4	25.4	84.9	8.5	8.5	9.3	174.1	63.7	8.5	25.5	21.2	6.4
	0.8	4.2	169.9	4.2	8.5	8.5	212.3	25.5	4.2	10.6	42.5	6.4
E_n	0.8	4.2	127.4	8.5	8.5	4.2	297.2	29.7	4.2	2.1	42.5	6.4
	0.8	4.2	84.9	12.7	8.5	4.2	382.2	25.5	2.1	2.1	42.5	4.2
	2.5	4.2	84.9	8.5	8.5	12.7	382.2	152.9	6.4	2.1	17.0	19.1

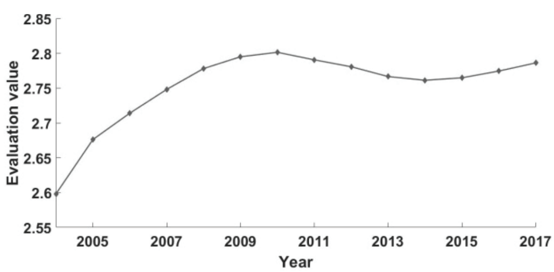

Fig. 2: Trend of water environment carrying capacity in Beijing.

Table 4: The evaluation results.

Year	2004	2005	2006	2007	2008	2009	2010
Result	2.598	2.676	2.714	2.748	2.778	2.795	2.801
Year	2011	2012	2013	2014	2015	2016	2017
Result	2.791	2.781	2.767	2.761	2.765	2.774	2.786

Compared with other years, the total amount of water resources in 2014 was relatively low. Although the technical level was improved, the carrying capacity was slightly reduced due to the great influence of climate on the water resource environment. The carrying capacity increased slowly after 2014, and the ecological water use rate showed a trend of rapid growth after that year. The forest coverage rate also increased slowly since 2013, indicating that people are more and more aware of the importance of environmental protection. Besides, the implementation of the south-to-north water diversion project can relatively alleviate the water pressure in Beijing. From 2015 to 2017, the chemical aerobic discharge has a tendency to decrease, which also alleviates the pressure on the water environment to some extent. However, due to the limitation of large population base and other factors, the carrying capacity has not been significantly improved.

CONCLUSIONS

In this paper, an evaluation index system is constructed based on the model of Driving Force-Pressure-State-Response. Entropy weight method can reduce the interference of human factors on weight distribution, and cloud theory can effectively take into account the fuzziness and randomness of concepts. Both methods have relatively objective results. Through the analysis of the evaluation model established by the organic combination of the two methods, relatively reliable evaluation results can be obtained. Although the carrying capacity level in Beijing in recent years has been improved to a certain extent, the overall state is still overloaded. The pressure on its sustainable use of water resources remains high. As a mega-city with a large population, Beijing is faced with problems such as water shortage and large population pressure. Therefore, while vigorously developing economy and urban construction, we should avoid pursuing economic growth and neglecting the negative impact of population concentration. We should give full play to the role of economic leverage, according to the needs of economic and social development "selective" to attract the population, increase the non-capital function evacuation, and reduce the mismatch of resources waste, to obtain the greatest social, economic and ecological benefits.

ACKNOWLEDGEMENTS

This work was supported by the National Key R& D Program of China (Grant No. 2016YFC0401406), and the Famous Teachers Cultivation planning for Teaching of North China Electric Power University (the Fourth Period).

REFERENCES

Han, Y., Zhang, S.F. and Lv, A.F. 2018. Study on the impact of foreign water transfer on the carrying capacity of water resources in Beijing, Tianjin and Hebei. Resource Science, 40(11): 2236-2246.

Huang, X., Chen, H.T. and Guan, Z.Y. 2017. Study on water environmental carrying capacity based on improved catastrophe theory. Nature Environment and Pollution Technology, 16(4): 1223-1228.

Liu, W. 2018. Study on the change of ecological environment carrying capacity- taking Beijing as an example. Price Theory and Practice, (09): 74-77.

Ni, X.P. 2018. Research on the navigation safety evaluation of Bayuquan harbor based on cloud theory. Dalian Maritime University.

Qi, X. and Zhao, Q. 2016. Water environment carrying capacity evaluation in Beijing. Ecological Economy, 32(02): 152-155.

Qu, H., Bao, J.L. and Zhang, W. 2017. Analysis and prospect of water environment bearing capacity. Journal of Hebei University of Geosciences, 40(5): 25-30.

Shao, N.H. 2018. Application of uncertainty reasoning model based on cloud theory in runoff prediction. Water Technology and Economy, 24(9): 62-66.

Song, D.Y. 2016. Countermeasure study on sustainable utilization of tourism resources and tourism environmental pollution in coastal areas of the Pearl River Delta, China. Nature Environment and Pollution Technology, 15(3): 873-879.

Wang, C.H., Hou, Y.L. and Xue, Y.J. 2017. Water resources carrying capacity of wetlands in Beijing: analysis of policy optimization for urban wetland water resources management. Journal of Cleaner Production, 161: 1180-1191.

Wang, H., Yu, W.X. and Jia, Y.Z. 2018. Comprehensive evaluation of water resources carrying capacity of Zhengzhou city. Water Conservancy Economy, 36(6): 57-61,74.

Wang, L.P. and Li, S.Q. 2018. Research progress on resource and environment carrying capacity. Resource Development and Market, 34(5): 644-648.

Wang, Y. 2016. Research on carrying capacity of water resources in Xihe River basin based on SD model. Hydroelectric Power, 42(6).

Yuan, L.W. 2017. Study on comprehensive evaluation of driving safety of mountain road landscape based on cloud theory. Kunming University of Science and Technology.

Zhang, A., He, J. and Chen, X.N. 2017. Research on evaluation model of regional water resource carrying capacity based on cloud theory. Water Conservancy and Hydropower Technology, 48(1): 18-22.

Zhang, J.S., Hu, X.Z., Li, Q. and Kopytov, C. 2015. Evaluation and comparison of the resource and environmental carrying capacity of the 10 main urban agglomerations in China. Nature Environment and Pollution Technology, 14(3): 573-578.

Zhang, Q. 2018. Research methods and development trend of water environment carrying capacity analysis and discussion. Chemical Management, (31): 101-102.