The Evaluation of Sustainable Utilization of Water Resources Based on Improved Catastrophe Progression Method

-----A Case Study in Dalian City

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Abstract. In this paper, entropy weight method is used to sort the indicators, which can avoid human subjectivity. As a typical coastal city, Dalian is selected as a case study to verify the applicability of the method. A water resource sustainable utilization index system including 15 indicators is built which involves water resource, society, economy and environment. The improved catastrophe progression method is provided and used to evaluate sustainable utilization of water resources situation in Dalian from 2002 to 2012. Results indicate that except 2002, the sustainable utilization index of water resources is around 0.8 from 2003 to 2012, which shows a strong degree of sustainability. The results are found to be coincident with practical situation, so it proves that the improved catastrophe progression method has good applicability.

Introduction

Water resources shortage is a serious problem all over the world. The concept of sustainable development has been put forward by the world commission on environment and development (WCED) since 1987 [1]. Many countries' governments and relevant experts pay attention to the water sustainable development and utilization because it is the most important measure to guarantee the sustainable development of economy, society and environment. Water resource scarcity is becoming more and more serious and greatly restricts sustainable development in many parts of our country, especially in coastal areas, which directly affects the sustainable development of China's economy and society.

China will be on the verge of water-stressed countries by the middle of the 21st century. In order to achieve the sustainable development and modernization, we should take integrated and effective counter-measures in various parts of water from development to utilization, from protection to management to improve the efficiency while water conservation [2]. Cornelis compiles a comprehensive list of indicators which have been subdivided into eight broad categories in the absence of dedicated framework to assess the sustainability of urban water management [3]. Keishiro proposes a method of sustainability evaluation consisting of three components: environment, resource, and socioeconomic with aggregated time-series scores and carry out a case study of Chinese provinces for the years 2000 and 2005 using this method and confirmed its applicability as the indicative type of sustainability evaluation at the regional level, while actually investigating the sustainability status and its chronological changes [4]. Ertug use water footprint to analyze how French water resources are allocated over various purposes, and examine impacts of French production in local water resources. In addition, they analyze the water dependency of French consumption and the sustainability of imports [5]. Based on systematical analysis, an index system together with the criteria for evaluation is developed, and a comprehensive method is proposed for evaluation of the status of sustainable utilization of urban water resources. A case study is presented, in which comprehensive evaluation is conducted to show the sustainable utilization level of water resources of Nanjing from1990 to 1999 [6].

According to the research above, water resource management research mainly focused on water quality and quantity in macro aspects including river basin, nation and region while relatively few cases of urban water resource research were studied. In terms of coastal cities, representative indicators were lacked. On the other hand, the majority of water resource research methods tend to be subjective lacking the objective example simply from data to result. In order to solve the problems above, a primary index of coastal city was established based on extensive literature index systems. Entropy weight method was applied to sort the indicators based on the data avoiding the subjectivity of human prioritization of indicators and catastrophe progression method was used to evaluate sustainable utilization of water resource situation of Dalian city from 2002 to 2012 so that the uncertainty and accuracy of the evaluation results were reduced and improved respectively.

Sustainable utilization evaluation model based on improved catastrophe progression method

Catastrophe Progression Method. The catastrophe progression method is based on the multi-level contradiction analysis; catastrophe theory and fuzzy mathematics are combined to set up catastrophe fuzzy membership function. Normalization formula is applied to comprehensive quantification, and a parameter can be got after normalization, that is, a general membership function. As a result, it is natural to get the comprehensive evaluation results. Weight is not used to sort the indicators in catastrophe progression method while the relative importance of indicators is concerned. The steps of catastrophe progression method are as followed:

A.*Establish evaluation index system of catastrophe progression method and decide prioritization*

According to the specific need, the general objective is decomposed into a multi-layer system which included a number of indexes, making the system like an inverted tree from the total index to sub-layer indexes, finally to the lowest sub-indicators. Commonly, the number of each layer's index is less than 4 in a catastrophe system. The prioritization, that is, the importance of each indicator should be decided. The paper uses entropy weight method to calculate the prioritization instead of personal experience traditionally. The details are in Entropy Weight Method part.

B. *Search for the index values and conduct standard processing towards the initial data*

Search for the accurate value for each indicator in the first place. According to the searched evaluation indicator values in the system, it is necessary to carry on standard processing towards the initial data ahead of catastrophe comprehensive evaluation. Positive and negative indicators should both be changed into positive indicators with normalization method.

C. *Determine the type of the catastrophe system and its normalized formula*

There are 3 most common types of the catastrophe system which are Cusp Catastrophe, Swallowtail Catastrophe and Butterfly Catastrophe. Their models and normalized formula are in table 1[7, 8].

Table 1 basic catastrophe types and normalization formula

Type	Potential function	Normalization formula
Cusp catastrophe system	$f(x)=x^4+ax^2+bx$	$x_a=(a)^{\frac{1}{2}}$, $x_b=(b)^{\frac{1}{3}}$
Swallowtail catastrophe system	$f(x)=\frac{1}{5}x^5+\frac{1}{3}ax^3+\frac{1}{2}bx^2+cx$	$x_a=(a)^{\frac{1}{2}}$, $x_b=(b)^{\frac{1}{3}}$, $x_c=(c)^{\frac{1}{4}}$
Butterfly catastrophe system	$f(x)=\frac{1}{6}x^6+\frac{1}{4}ax^4+\frac{1}{3}bx^3+\frac{1}{2}cx^2+dx$	$x_a=(a)^{\frac{1}{2}}$, $x_b=(b)^{\frac{1}{3}}$, $=(c)^{\frac{1}{4}}$, $x_d=(d)^{\frac{1}{5}}$

D. *Conduct comprehensive evaluation by normalized formula*

The x that calculates from normalization formula of each indicator should use minimax principle or average value principle. The minimax principle is used when the indicators can't instead each other or totally independent. Choose the smallest one as the x of the whole system or sub-system from x_a, x_b, x_c, and x_d. The average value principle is used when the indicators can instead each other in some extent or has some relationship. Count the average value of x_a, x_b, x_c, and x_d to be the x of the whole system or sub-system.

Entropy Weight Method. Indicators are often sorted according to their weights. In the process of existing indicator evaluations, some subjective ways such as expert survey method, Delphi method, AHP, etc., are often used to weigh the indicators. However, when the subjective methods are used, they may result in deviations of indicators' weights due to subjective factors, thus leading to uncertainty of some indicators. Entropy is usually used to measure the degree of disorder or dispersion for a closed system and it is an excellent indication of concentration or uncertainty. The smaller the entropy value is, the smaller the disorder degree of the system is. As an objective weight method, entropy weight method determines the indicator weight based on data. In this paper, the entropy weight method is adopted to determine the weight of the indicators, which is calculated as following.

Assume that the original matrix as following is composed by m samples and n indicators.

$$R=(r_{ij})_{m*n,} i=1……m; j=1……n \quad (1)$$

r_{ij} represents the j^{th} indicator of the i^{th} sample.

Use extremum method to make indicators being dimensionless.

$$\begin{cases} r'_{ij}=\frac{r_{ij}-r^j_{min}}{r^j_{max}-r^j_{min}}\alpha+\beta, & \text{wherer } r_{ij} \text{ is a positive indicator} \\ r'_{ij}=\frac{r^j_{max}-r_{ij}}{r^j_{max}-r^j_{min}}\alpha+\beta, & \text{where } r_{ij} \text{ is a negtive indicator} \end{cases} \quad (2)$$

α and β are bound parameters which are selected 0.9 and 0.05 relatively to normalize the data to 0.05-0.95. r^j_{max} and r^j_{min} are relatively the maximum and minimum of the j^{th} indicator. In term of moderate indicator, it can be treated as a positive indicator when its value is lower than the standard value and vice versa.

The entropy weight of the j^{th} indicator can be computed by:

$$e_j=-K\sum_{i=1}^{m} y_{ij}\ln y_{ij}, \quad i=1……m; j=1……n \quad (3)$$

$$K=\frac{1}{\ln m}, \quad y_{ij}=\frac{r'_{ij}}{\sum_{i=1}^{m} r'_{ij}} \quad (0\le y_{ij}\le 1)$$

The coefficient of variation of the j^{th} indicator can be computed by:

$$d_j=1-e_j \quad (4)$$

Case Study

Dalian as a coastal city was selected to be the study case in order to describe the application of the improved catastrophe progression method in details.

Case Description. Dalian city in Liaoning Province, northeast China is a typical coastal city selected to be the study case in this paper. Dalian city encompasses 12574 km^2 and is one of the important economic and trade exchanges channel in Northeast Asia. It is bounded by the coordinates 120°58' - 123°31' E, 38°43' - 40°10' N in Southern Liaoning Province. The main geomorphological type in Dalian city is hills and mountains. The coastline of Dalian city is about 2211 km long. There are more than 200 rivers in Dalian city such as Biliu river, Yingna river etc. and many of them are ephemeral stream. The water resources average capacity in Dalian city is 9.1 billion cubic meters, the average elevation is 20-60 m. This region has a temperate humid monsoon continental climate; average annual rainfall is 550-950 mm and average annual temperature is 10.5°C.

Establish the Index System. An index system refers to an organism consisting of several related statistical indicators. The sustainable exploitation and utilization of regional water resources relates to not only its natural distribution but also its population, economy and environment. Therefore, the principles related to population, economy and environment when establishing an index system must be concerned thus leading to a specific, comparable, objective, practical and effective principle.

In the paper, concerning the characteristic of water resources in Dalian City and the availability of the data, an index was established on the basis of extensive literature index systems. The index involves 4 subsystems such as water resource, society, economy and environment including 15 indicators. They are C_1: per capita water resources; C_2: seawater intrusion index; C_3: water resources exploitation and utilization; C_4: the ratio of water reuse and desalination of water to the total water supply; C_5: urbanization level; C_6: population natural growth rate; C_7: population density; C_8: per capita daily water consumption; C_9: proportion of tertiary industry; C_{10}: per capita GDP; C_{11}: water supply production capacity; C_{12}: per capita GDP water consumption; C_{13}: industrial wastewater discharge compliance rate; C_{14}: urban sewage treatment rate; C_{15}: green coverage rate. The data in the paper were all from statistical yearbook and water resource bulletin in 2002-2012[9, 10]. The original data was shown in table 2.

Table 2 Indicator data of sustainable utilization of water resources in 2002-2012 in Dalian City

Year / Indicator	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
C_1	114	222	494	726	388	530	341	241	669	652	1194
C_2	3.2	3.2	3.8	3.7	4.0	6.8	6.9	7	5.1	5.2	4.9
C_3	146.14	70.56	32.47	28.23	51.6	39.99	65.39	101.77	39.35	42.38	22.84
C_4	0.2	0.3	1.6	3.1	2.5	2.1	2.5	7.7	7.0	9.2	9.9
C_5	50.5	51.6	53.1	56.2	56.2	58.3	59.6	61.2	62	62.5	62.8
C_6	1.16	-0.54	0.68	0.4	-0.04	1.65	1.25	1.17	1.72	1.48	3.14
C_7	444	445	447	450	455	460	464	465	466	468	469
C_8	209	239	288	303	234	224	258	269	274	245	218
C_9	47	46.2	46	45.9	44.5	43.7	43.9	43.9	42.7	41.5	41.7
C_{10}	2.4	2.77	3.3	3.44	4.06	4.83	5.89	6.65	7.77	9.13	10.29
C_{11}	127.7	144.6	144.6	143.7	169.2	171.7	171.7	165.5	164.4	169.4	163
C_{12}	66	54	46	51	45	39	34	32	30	26	23
C_{13}	97.1	96.5	97.2	97.8	97.9	96.3	97	95.3	95.3	95.56	95
C_{14}	75.7	87.9	89.4	73	73.3	90	90	90.4	79.2	93.74	95.1
C_{15}	41.5	41.8	42.4	42.77	42.8	43.31	44	44.8	45	45.1	45.2

Evaluation and Analysis. Based on the original data collected from the statistical yearbook and water resource bulletin in 2002-2012, the entropy weight is calculated by the entropy weight method which is shown in table 3.

Table 3 Indicator entropy value table of sustainable utilization of water resources in Dalian City

Criterion Layer	Indicator Number	Entropy Weight	Criterion Layer	Indicator Number	Entropy Weight
water resource	C_1	0.083942	economy	C_9	0.081034
	C_2	0.095843		C_{10}	0.111028
	C_3	0.080624		C_{11}	0.051805
	C_4	0.120951		C_{12}	0.052290
society	C_5	0.127021	environment	C_{13}	0.090878
	C_6	0.073927		C_{14}	0.091889
	C_7	0.116201		C_{15}	0.083287
	C_8	0.062637			

The indicators in each sub-system were Sorted based on the comparison of the entropy weight. The order in water resource sub-system is $C_5>C_3>C_1>C_4$; order in society is $C_6>C_8>C_7>C_9$; order in economy is $C_{12}>C_{11}>C_{13}>C_{14}$; order in environment is $C_{16}>C_{15}>C_{17}$. The index of sustainable utilization of water resources in Dalian City is shown in figure 1.

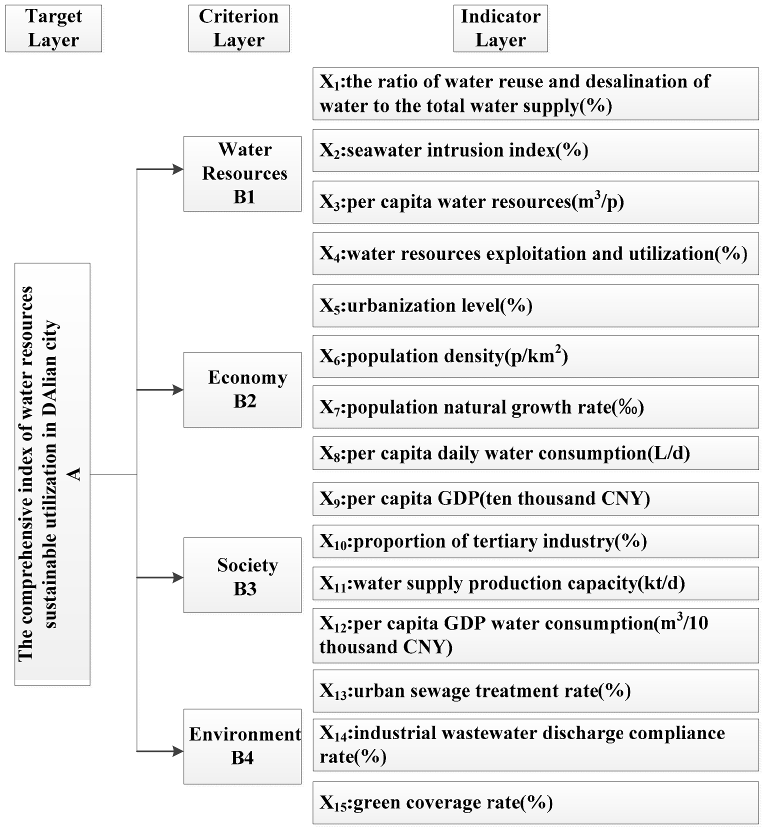

Fig.1 Index of sustainable utilization of water resources in Dalian City

Based on the index, the paper calculates the data with catastrophe progression method and the results are shown in table 4.

Table 4 Evaluation result of sustainable utilization of water resources in 2002-2012

Year	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Result	0.500	0.806	0.864	0.836	0.857	0.807	0.776	0.759	0.871	0.879	0.840

The trend of sustainable utilization of water resources in 2002-2012 is shown in figure 2 in order to get the result clearer.

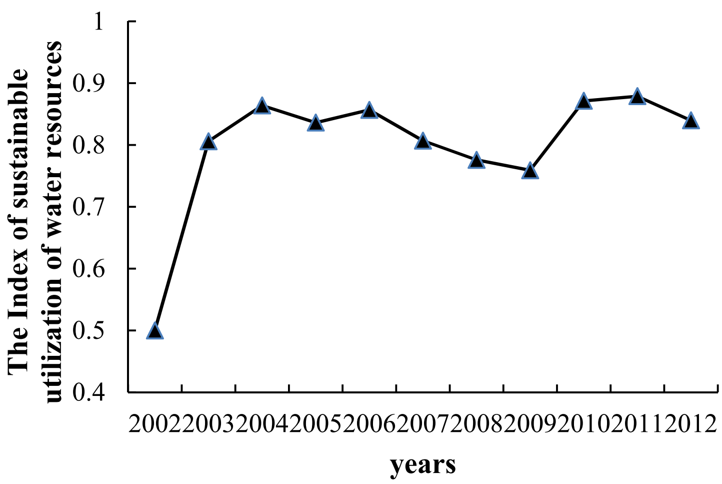

Fig.2 The trend of sustainable utilization of water resources in 2002-2012

We can draw a conclusion that the result of water resource sustainable utilization in 2002 is the lowest in 2002-2012 which is 0.500 and it sharply goes up to 0.806 in 2003 and turns out to be around 0.800 in the following years were shown in figure 2. According to the sustainable utilization of water resources grade in table 5, except for the result in 2002 which is extremely weak, the result of the other years are all strong sustainable utilization, which demonstrates that the level of sustainable utilization in Dalian City tends to be high.

Table 5 Sustainable utilization of water resources grade [11]

Grade	extremely weak	weak	medium	strong	extremely strong
Result A	A≤0.3	0.5≥A≥0.3	0.7≥A≥0.5	0.9≥A≥0.7	A≥0.9

Looking back to the development of water resource field since 2002, there has been an earthshaking change. Before the "Yin Ying Ru Lian" project which means introducing the Ying Na river to Dalian City (short for Project below), the utilization of water resources in Dalian City showed an increasingly tense situation, where urban domestic water and agricultural production water are not that plenty. But after 2003, faced with the tense situation, local government made a decision to carry out the Project immediately and mobilized the residents to save water resources. With the implementation of the Project and the water-saving policies, the situation of water resources in Dalian city gets improved, leading to a stable sustainable utilization of water resources.

According to the facts and the result analysis, the result is found to be coincident with practical situation, so it proves that the improved catastrophe progression method works well.

Conclusion

A water resources sustainable utilization index including 15 indicators was built which involved water resource, society, economy and environment based on entropy weight method which was used to sort the indicators reasonably avoiding the subjectivity of human prioritization of indicators.

The improved catastrophe progression method was used to evaluate sustainable utilization of water resources situation in this paper. Through the research above, we come to a conclusion that the other years' sustainable utilization index of water resources turned out to be around 0.8 except the year 2002, which indicated a strong degree of sustainability based on the result analysis. The result was found to be coincident with practical situation, so it proves that the improved catastrophe progression method works well.

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