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Study on Evaluation of Water Ecological Carrying Capacity

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***Abstract*—The index system of water ecological carrying capacity (WECC) is constructed based on Pressure-State-Response model. In light with the calculation of water ecological carrying capacity in different years, the development tendency of WECC in Liaoning Province is analyzed. It concludes that WECC of Liaoning is lower than that of national average. It is thought that the shortage of water resources is the limitation of the water environment in Liaoning. Finally, some effective suggestions to improve the WRCC of Liaoning are proposed.**

Keyword: water ecological carrying capacity; index system; Pressure- State-Response model; Liaoning

I. INTRODUCTION

With rapidly increasing of population and development of economy, overuse of water resource makes water ecological environment worsen. Water ecological carrying capacity (WECC) is a threshold value that persistently supports development scale of economy and society in the context of environmental condition and in the one historical phase, on the condition of water ecological system of one watershed meeting a need of its own good development [1]. WECC can accurately reflect on function and reflection among water ecological system, society and economy, and provide decision-maker with some basic data and analytic conclusion, as one of macro-control instrument of decision-maker and supervisor [2]. How to evaluate WECC is regarded as a principal matter of water environment management. So far, study on WECC is focused on use of water resource, especially quantity of water resource. However, quality of water resource is important as well as quantity of water resource in the evaluation of WECC. In this paper, the index system of WECC is constructed with PSR model, based on considering present situation of water environment, press of water resource and pollution from development of society and economy, and response on press of water environment from decision-making.

II. DESIGN OF EVALUATION INDEX SYSTEM ON WATER ECOLOGICAL CARRYING CAPACITY

The design of evaluation Index system on water ecological carrying capacity would describe the size and status of ecological carrying capacity. Evaluation Index system not only can reflect the water pressure level of the number of aquatic ecosystems and quality, but also reflect the pressure level of the socio-economic system. In addition, it can reflect the ecological system to the ecological capacity of water, and reflect the level of coordination between water system, social system, economic system and ecological system. This must be based on the correct understanding to the number, quality and dynamic changes of the regional water resources, and the regional social, economic size, structure and development trend roundly.

The design of the Indicators should comply with the following principles [3]: (1) the principle of that the meaning of water ecological carrying capacity should be fully reflected: it should clarify the size and status of the regional water ecological carrying capacity, and embody harmony of the system and healthy development of ecological environment. (2) the systematic principle: water ecological carrying capacity system is a complex multi-attribute system that relates to the water environment, economic and social development, ecological environment protection level, water resource and so on. They have very complex linkages, and the selected indicators should be able to fully describe the system. (3) the hierarchy principle: as the water ecological carrying capacity system is a complex giant system. Evaluation Indicators involves many aspects, and each side also has many factors. Indexes have a certain level and subordinate relation. For the evaluation in different levels, different indicators are selected to describe. (4) the operational principle: the number of indicators in the index system should not be too many. It should consider both comprehensive and simplicity to the system, and control the degree of representation and operability. Moreover, the indicators in the index system of should be simple and easy to understand. Usually they would be expressed by per capita, percentage, growth rate, effectiveness, etc., and have good comparability. (5) Comparability principle: Index system would transform the relation between water resources, social, economic and ecological systems into the measured, calculated, compared data and numerical, in order to analyze and formulate relevant policies to provide quantitative data.

III. THE ESTABLISHMENT OF INDEX SYSTEM ON WATER ECOLOGICAL CARRYING CAPACITY OF BASED ON P-S-R FRAMEWORK

In the late 1980s, the Organization for Economic Cooperation and Development (OECD) and the United Nations Environment Program (UNEP) jointly proposed the

P-S-R conceptual model for environmental indicators which means Pressure-State-Response Model [4]. In P-S-R framework, the environmental problems can be described as three different but interrelated types of indicators: Environmental load which is brought by human activities can be reflected by pressure indicators. Environmental quality, natural resources and ecosystem conditions can be characterized be state indicators. Strategies and measures taken by humans facing the environmental problems can be characterized by response indicators. Studying the interaction of human and environmental system, the environmental indicators can be organized and classified by P-S-R conceptual model which is highly systematic. Based on this, the designed indicators can preferable reflect the interdependent and mutually constraining relations among nature, economic, environment, resources [5]. At present, P-S-R assessment model has been widely applied to ecological security assessment [6], industrial pollution assessment [7], wetland health assessment [8] and other fields.

Based on the guiding ideology and principles of the evaluation index system on water ecological carrying capacity, the index system on water ecological carrying capacity is established according to P-S-R framework, referring to the current index system [9]. The state indicators level is constructed by regional state and water state. The pressure indicators level is constructed by population, economic level and pressure of economic development. The response indicators level is constructed by capability and measures of social response. The indicators are as follows:

1) *State indicators*

a) Population density: It means regional population per unit of area, which can characterize population pressure.

b) Forest coverage rate: It means the proportion of forest to the total area, which can reflect the level of regional forest resources and afforest. It can characterize the conservation state of soil and water, and it is the basis of water renewal.

c) Usable water resources per capita: It characterizes the state of total regional water resources.

d) Utilization rate of water resources: It means the percentage of the consumption of socio-economic water to the total water resources (including industrial and agricultural water and residential water),which characterizes the state of water resources utilization.

e) Water production module: It means the water resources per unit area, which is a dynamic value,which characterizes the state of total water resources.

f) Effective irrigation area rate: It generally means the percentage of normal irrigation area to the total cultivated area in the next year, which characterizes the state of irrigation water utilization.

g) The net quantity of chemical fertilizers: It means the actual amount of fertilizers used for agricultural production this year, which characterizes the state of agricultural pollution.

2) *Pressure indicators*

a) Population growth rate: It means the rate of the natural population growth to average number of population during a given period,which characterizes the pressure on population growth.

b) GDP per capita: It characterizes the pressure on the overall regional economic development.

c) Urbanization rate: It means the rate of urban population to total population, which reflects the social development level and population quality.

d) GDP growth rate: It characterizes the pressure of the overall economic development level.

e) The proportion of primary industry: It means the proportion of primary industry to GDP, which reflects the condition of regional industrial structure.

f) The water consumption in industrial million outputs: It means the water consumption in producing 10,000yuan of industrial output values, which is used to measure the level of water consumption in different cities or industries, and it characterizes the pressure of water consumption on industrial development.

g) Water consumption rate of eco-environment: It means the proportion of ecological water consumption to total water resources, which reflects the pressure of ecological water consumption.

h) Domestic water quota: It means the daily water consumption per capita. It is the integrated water indicator, which reflects the condition of the population quality and water conservation., and it characterizes the pressure on domestic water.

i) Dilution ratio: It means the proportion of average of wastewater to the average runoff, which characterizes the damage pressure on sewage disposal to water resources.

j) Irrigation water quota: It means irrigation water consumption per unit area, which is used for measuring the level of agricultural water, and ir characterizes the water consumption pressure on agricultural development.

3) *Response indicators*

a) The proportion of investment in pollution control to GDP: It reflects the condition of investment in pollution control, and it characterizes the capability of managing the environmental pollution.

b) The attainment rate of industrial wastewater: It means the proportion of compliance discharge of industrial wastewater to total discharge of industrial wastewater, which characterizes the capability of managing the pollution of industrial wastewater.

c) The recycling rate of industrial water: It means the proportion of recycling water consumption to total water consumption, which characterizes the level of conservation of industrial water.

d) The proportion of water saving irrigation: It means coverageof water saving irrigation facilities, which characterizes the level of conservation of agricultural water.

IV. CAST STUDY

Liaoning Province is studied as a case in this paper. Based on the actual values of Liaoning Province from 2005 to 2008 and the actual values of nation wide in 2008, the water ecological carrying capacity is calculated. The data are obtained by *2006-2009 Statistical Yearbook of Liaoning Province*, *2006-2009 Bulletin of water resources in Liaoning Province*, *2006-2009 China Environment Statistical Yearbook* etc. The specific values are shown in Table 2.

A. Index standardization, selection of standard indicators and determination of weight

Each indicator in the evaluation index system generally has its own dimensions, so it cannot be compared and calculated directly. It must be standardized. Each indicator should be transformed by the method of effectiveness factor scores in this paper shown in equations (1), (2). The selection of standard values of indicators should comply with the following principles: Towards to the currently existed index values which are generally recognized, such as international, national recognized standard values, the index values of development plan issued by nation or region , etc; Towards to the individual indicators which have not been openly index values, it can be determined the scope of its theoretical values according to the definitions and meanings of individual indicators, and it should be reasonable formulated considering the development characteristics and trends of national and international indicators; the specific options are shown in Table 2.

Indicators of positive effects: *Determining the number of evaluation indicators is m. If the first p indicators have positive effects, the j-index of the i-object would be valued as* X_{ij}' *, and the standardized value of it would be:*

$$X_{ij}' = \frac{X_{ij} - \min(X_{ij})}{\max(X_{ij}) - \min(X_{ij})} \quad (1)$$

（i=1, 2, …, P; j=1, 2, …, p）

Indicators of negative effects: *If the last(m-p) indicators have negative effects, the standardized value of j-index of the i-object would be:*

$$X_{ij}' = \frac{\max(X_{ij}) - X_{ij}}{\max(X_{ij}) - \min(X_{ij})} \quad (2)$$

（i=p+1, p+2,⋯, m; j=p+1, p+2, ⋯, m）

In the equations, X_{ij}' are the standardized values of the indicators; $\max(X_{ij}')$ are the maximum values of the indicators; $\min(X_{ij}')$ are the minimum values of the indicators; p is the number of the positive assessment indicators; m is the total number of the indicators; when $X_{ij}' = 1$, the values of the indicators are at their best; conversely, when $X_{ij}' = 0$, the values of the indicators are at their worst.

The comprehensive evaluation methods which are common used in assess the resources carrying capacity and water ecological carrying capacity are experts rating method, analytic hierarchy process, fuzzy comprehensive evaluation method, principal component analysis, projection pursuit procedure method, etc. The AHP method is used in this paper, the weight of each indicator is calculated to determine the structure of compassion matrix, and the consistency test should be taken.

B. The calculation model for comprehensive indicators of water ecological carrying capacity

The calculation model for each level of indicators is as follows:

$$\mathrm{Y} = \sum_{\mathrm{i}} \mathrm{W}_i X_i \quad (3)$$

In the equation, Y is the comprehensive evaluations of each level of indicator; X_i, W_i are the weight of the assess value of i indicator and index factor respectively.

According to other evaluation index system methods, the standard of water ecological carrying capacity can be divided as Table 1.

TABLE I. GRADE STANDARD OF WATER ECOLOGICAL CARRYING CAPACITY

Capacity rating standard	*Low*	*Medium*	*High*	*Very high*
Target range	≤0.4	0.4~0.6	0.6~0.8	≥0.8

C. The results of calculating indicators of water ecological carrying capacity

The weight of each indicator is calculated by the above method. By using the index data from 2005 to 2008 given in Table 2, the indices are obtained through normalization. The specific results are shown in Table 3.

TABLE II. REFERENCE VALUE OF EACH INDEX AND ACTUAL VALUE BETWEEN 2005-2008

Criteria level	Index level	Type	High value	Low value	Nation 2008	Liao 2008	Liao 2007	Liao 2006	Liao 2005
State	***Population density (person/km^2)***	Negative	25	300	138	287	286	284	283
	Forest coverage rate (%)	Positive	50	10	18.21	32.97	32.97	32.97	31.84
	Usable water resources per capita (m^3/person)	Positive	8000	500	2071.1	617.7	610.8	620.8	896.2
	Utilization rate of water resources（%）	Negative	10	60	21.1	53.67	54.59	54.03	35.33

	Water production module ($10^4m^3/km^2$)	Positive	60	15	28.58	17.98	17.68	17.66	25.49
	Effective irrigation area rate (%)	Negative	10	60	48.04	36.55	36.5	36.72	37.33
	The net quantity of chemical fertilizers （kg/hm^2）	Negative	200	550	430.4	315.3	312.1	296.7	293.1
Pressure	***Population growth rate (‰)***	Negative	2	20	11.45	1.4	2.4	2.3	2.0
	GDP per capita (Yuan)	Negative	3000	77400	22698	31258	25729	21788	18983
	Urbanization rate (%)	Negative	20	70	45.68	49.9	49.05	48.85	48.45
	GDP growth rate (%)	Negative	2	9	9.0	13.1	14.5	13.8	12.3
	The proportion of primary industry (%)	Negative	3	30	11.3	9.67	10.3	10.6	11.0
	The water consumption in industrial million outputs （$m^3/10^4$yuan）	Negative	15	300	127.00	36.61	46.83	56.38	60.44
	Water consumption rate of eco-environment (%)	Negative	1	5	1.61	1	0.97	0.73	0.29
	Domestic water quota [L/(d· person)]	Negative	100	300	150.46	158.47	157.45	157.8	156.44
	Dilution ratio (%）	Negative	1	10	2.17	9.34	9.52	9.1	6.5
	Irrigation water quota (m^3/hm^3)	Negative	5500	11000	6265	5769	6148	6102	5707
Response	***The proportion of investment in pollution control to GDP (%)***	Positive	1.7	0.2	1.49	1.87	1.13	2.18	2.14
	The attainment rate of industrial wastewater (%)	Positive	100	80	92.4	88.39	92.41	92.91	95.09
	The recycling rate of industrial water (%)	Positive	90	40	83.8	75	72	70	68
	The proportion of water saving irrigation (%)	Positive	70	10	41.79	29.05	27.36	26.86	25.20

TABLE III. WEIGHT VALUE OF EACH INDEX AND VALUE OF TARGET INDEX

Criteria level	Index level	Nation2008	Liao2008	Liao2007	Liao2006	Liao2005	Division weight	Global weight
State 0.559	***Population density (person/km^2)***	0.07656	0.00614	0.00665	0.00733	0.00801	0.2329	0.130
	Forest coverage rate (%)	0.00649	0.01817	0.01817	0.01817	0.01727	0.0567	0.032
	Usable water resources per capita (m^3/person)	0.01840	0.00138	0.00130	0.00141	0.00464	0.1574	0.088
	Utilization rate of water resources（%）	0.06481	0.01055	0.00901	0.00995	0.04110	0.1493	0.083
	Water production module ($10^4m^3/km^2$)	0.05328	0.01169	0.01051	0.01044	0.04116	0.3164	0.177
	Effective irrigation area rate (%)	0.00555	0.01089	0.01091	0.01081	0.01052	0.0416	0.023
	The net quantity of chemical fertilizers （kg/hm^2）	0.00869	0.01706	0.01729	0.01841	0.01868	0.0456	0.025
Pressure 0.319	***Population growth rate (‰)***	0.04294	0.09341	0.08839	0.08889	0.09040	0.2825	0.090
	GDP per capita (Yuan)	0.02468	0.02082	0.02331	0.02509	0.02636	0.1049	0.034
	Urbanization rate (%)	0.00459	0.00379	0.00396	0.00399	0.00407	0.0295	0.009
	GDP growth rate (%)	0.00000	-0.01659	-0.02225	-0.01942	-0.01335	0.0885	0.028
	The proportion of primary industry (%)	0.00698	0.00759	0.00735	0.00724	0.00709	0.0315	0.010
	The water consumption in industrial million outputs（$m^3/10^4$yuan）	0.03094	0.04711	0.04528	0.04357	0.04285	0.1593	0.051
	Water consumption rate of eco-environment (%)	0.00833	0.00982	0.00990	0.01049	0.01157	0.0307	0.010
	Domestic water quota [L/(d· person)]	0.01206	0.01141	0.01150	0.01147	0.01158	0.0504	0.016
	Dilution ratio (%）	0.00855	0.00072	0.00052	0.00098	0.00382	0.0307	0.010
	Irrigation water quota (m^3/hm^3)	0.05292	0.05847	0.05423	0.05474	0.05916	0.1921	0.061

Response 0.122	***The proportion of investment in pollution control to GDP (%)***	0.04782	0.06191	0.03448	0.07340	0.07192	0.4558	0.056
	The attainment rate of industrial wastewater (%)	0.01063	0.00720	0.01064	0.01107	0.01294	0.1406	0.017
	The recycling rate of industrial water (%)	0.02811	0.02246	0.02054	0.01925	0.01797	0.263	0.032
	The proportion of water saving irrigation (%)	0.00909	0.00545	0.00496	0.00482	0.00435	0.1406	0.017

D. Results analysis

The comprehensive evaluation values of water ecological carrying capacity in Liaoning Province from 2005 to 2008 are obtained by Table 3 and formula (3) are shown in Table 4.

TABLE IV. EVALUATION RESULTS OF WATER ECOLOGICAL CARRYING CAPACITY

TABLE V. BETWEEN 2005-2008, LIAONING

Year	**State**	**Pressure**	**Response**	**Evaluation value**	**Capacity level**
Liao2005	0.25338	0.76106	0.87848	0.492	medium
Liao2006	0.13713	0.70955	0.88972	0.412	medium
Liao2007	0.13235	0.69435	0.57884	0.367	low
Liao2008	0.13598	0.73926	0.79518	0.409	medium
Natione2008	0.41898	0.59997	0.78404	0.521	medium

As can be seen from the table, the water ecological carrying capacity in Liaoning Province is declined, and the overall carrying capacity is normal. From the state evaluation value, it can be seen that the resources level is relatively low and the overall abundance of water resource is not high. It is at a lower level comparing to the national value. Although the pressure evaluation value is higher than the national value, that is. The level of socio-economic demand for water is lower than the national value, the water shortage is still the main factor which restricts the water ecological carrying capacity, and it has become an important factor which affects the economic development. In the response aspect, the response level of water resources in Liaoning Province is also slightly higher than that of the national level, and the inputs in pollution control and water conservation is also higher. Due to the not high state value of water resources, although there are some advantages in pressure and response aspects, the comprehensive evaluation value is lower than the national average level, and the overall water situation is not optimistic. Refer to the indicator values, the water conservation space in industry and agriculture in Liaoning Province is relatively large. The water efficiency in agriculture is still needed to improve. The proportion of industrial wastewater should be reduced. The recycling rate of industrial water should be increased. The coastal advantages such as mining of marine resources should be brought into play in Liaoning Province, which can improve the level of water resources state in Liaoning Province.

V. CONCLUSIONS

Evaluation index system on water ecological carrying capacity that based on PSR framework could fully reflect that the status of urban socio-economic, ecological environment and water resources related water resource carrying capacity and interaction between them. From the results of Liaoning Province example, the index system could reflect the basic situation of regional water ecological carrying capacity that provide the basis for determining the impact factor and the dominant factor of regional water ecological carrying capacity. Therefore, the index system has practical significance and provided theoretical support for regional water environmental management.

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