Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29134

281 (2023) 78–90
January

DPSRE model framework for dynamic evaluation of the water environment carrying capacity in a river network area of Taihu Lake, East China

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Received 6 July 2022; Accepted 17 November 2022

ABSTRACT

A reasonable evaluation index system is very important for the scientific assessment of the water environment carrying capacity (WECC). The framework system of driving force-pressure-state-response-economic benefit (DPSRE) and one-vote veto mechanism were proposed, which was used to construct an evaluation index system for WECC. The analytic hierarchy process (AHP) was employed to analyze the WECC of Changxing County in Taihu Lake Basin, China, during the years from 2010 to 2018 and different water periods (wet, flat, and dry) in 2018. The results showed that the WECC of Changxing County fluctuatingly increased from 2010 to 2018 and the evaluation grade varied from critical overload to loadable, with the maximum value of 0.71 (loadable) in 2016 and the minimum value of 0.50 (overload) in 2015 and 2018. In addition, the WECC was loadable during the wet (0.75) and flat (0.74) water period, while overload in the dry water period (0.50) in 2018. Through analysis the influence weights of indicators, development and utilization ratio of water resources, domestic sewage treatment compliance rate, output tax of per unit emission right, vegetation coverage rate of riverbank, aquatic plants coverage rate of river were the major indicators affecting the WECC. By analysis the evaluation results, the improvement of WECC was attributed to the increase of economic benefit subsystem. The water quality compliance rate of regional exit section (S_0) did not reach 100% was the real reason for the overload status of WECC in 2015, 2018 and the dry water period (2018). Ecological degradation of river and point and non-point source pollution were the most constraints to the WECC in Changxing County.

Keywords: Water environment carrying capacity; DPSRE model; Analytic hierarchy process; Taihu Lake Basin; River network area; East China

1. Introduction

With the advancement of industrialization and urbanization, most countries are facing water resources shortage, water environment pollution and water ecological damage problems, which restrict regional sustainable development [1]. Healthy development of the water environment is one of the most important factors for achieving sustainable development of regional socio-economic [2]. It is urgently needed to explore a way to keep water environment safety

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[3]. Recently, many researchers have explored the maximum scale and bearing capacity of regional water environment to support socio-economic sustainable development by evaluating water environment carrying capacity (WECC) [4]. Scientific evaluation for the WECC changes provide insights into regional water resources management, water environment optimization and water ecology restoration [5].

WECC was widely used in researches regarding water environment, such as Taihu Lake Basin [6], Bosten Lake Basin [7], Huaihe River Basin [8], Yongding River Basin [9], Yangtze River Economic Belt [10], Lake Okeechobee Basin [11]. However, most studies regarding WECC mainly focused on the overall watershed, but ignored the fine-grained control of the WECC in small watersheds. Besides, previous studies mainly analyzed the trend of inter-annual variation on the time scale, but the evolution trend of WECC in different water periods during the year was less addressed. Therefore, increasing attention has been drawn to the refined and differentiated management of regional WECC.

Constructing an objective and reasonable evaluation index system is important to the accurate assessment of WECC. An appropriate framework model is the premise to establish a scientific index system [12]. There is a lack of a unified index system for the assessment of WECC [10]. Commonly used models are as follows: pressure-state-response (PSR) [13], driving force-state-response (DSR) [14], and based on PSR and DSR methods, scholars proposed driving force-pressure-state-response (DPSR) [15], driving force-pressure-state-impact-response (DPSIR) [16], driving force-pressure-state-impact-response-management (DPSIRM) [17], etc.

PSR framework model was generally used for ecological environmental assessment [18], PSR is widely recognized and used [19]. However, the coupling relationship between socio-economic development activities and water environmental conditions is considerably complicated. In the process of WECC evaluation, PSR model ignored influence of economic benefit on various subsystems of water environment system, lacking reflection of high-quality green development in East China. Thus, driving force-pressure-state-response-economic benefit (DPSRE) method is proposed by newly introducing driving force and economic benefit subsystem into the PSR framework model. It contains five parts: driving force (D), pressure (P), state (S), response (R) and economic benefit (E). The DPSRE model reflects that the development of population and socio-economy is the driving force to promote the development of water environment. The development of the driving force subsystem results in environmental pressure. The increase of pressure changes the state of the water environment, which makes people a response to changes in the water environment state. Finally, it promotes the coordinated development of each subsystem through improving response and increasing the economic benefits of the water environment. The index system based on the DPSRE framework model reflects the causal relationship between water environmental health and socio-economic development.

The carrying capacity of water environment assessment based on the comprehensive index evaluation methods is widely used and readily applied [20]. However, there is limited applicability in assessing WECC due to regional difference. Further, we must account for the changes in water quality when assessing the WECC, due to the water environment management policy (the water quality of both control section and functional zone needs to reach the target) in East China [21]. At present, WECC mainly focuses on the research on the carrying capacity of the water environment in a comprehensive results [6–10], and seldom studies the key factors of the water environment on healthy development of social economy from the water quality target. Therefore, in order to avoid the influence of the water quality target on the evaluation results, the one-vote veto mechanism was employed to evaluate WECC.

Plain river network areas in East China are often influenced by human activities, and the water quality of these river networks is more sensitive to local human beings' production and living than that in other areas in China [22]. Water safety is a key factor in high-quality green development in East China [23]. Therefore, based on the DPSRE framework model, this study constructed the evaluation index system and proposed one-vote veto mechanism. The analytic hierarchy process (AHP) model was used to evaluate the WECC of Changxing County, China from year 2010 to 2018 and in different water periods (wet, flat and dry water period) in 2018, and study on the changing trend of WECC. The studied case could reveal the current situation of WECC and offer guidance to water environmental management and socio-economic development in the river network area in East China. The research flow chart of this study is shown in Fig. 1.

2. Materials and methods

2.1. Study area

Changxing County (30°43′-31°11′N, 119°33′-120°06′E), located in Taihu Lake in China, is a plain river network area in northern Zhejiang Province (Fig. 2), most rivers flow into Taihu Lake. The total length of all the main rivers in the study area is about 1,631 km, with a total area of 1,431 km^2. In 2018, the GDP of the whole region was about 60.98 billion yuan and the total population was 0.63 million. Changxing County was selected as the study area to introduce the regional WECC quantitative evaluation theory into a real-world case. The county has highly developed industries, especially advanced manufacturing, textile printing and dyeing industry, and chemicals industries, among others. Additionally, the Taihu Lake mainly takes in industrial wastewater, domestic sewage and non-point source pollution caused by the application of chemical fertilizers in Changxing County. As a result, pollution-induced water safety issues occur, and this region is proper for WECC limits research.

2.2. Data sources

The data resources include the Changxing County Statistical Yearbook, Huzhou Water Resources Bulletin, Huzhou Environmental Quality Bulletin, field investigation (sewage treatment plant, water-related enterprise and river) and the Geospatial Data Cloud (http://www.gscloud.cn/). The period covered in this study is from 2010 to 2018. The index data are shown in Table 1.

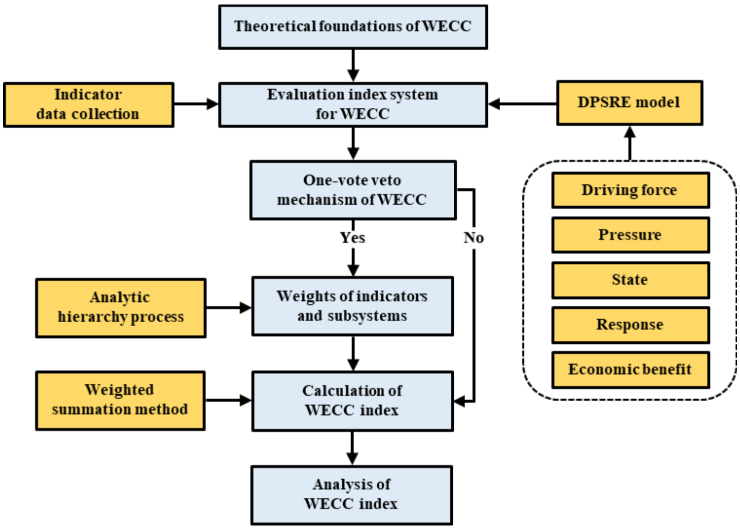

Fig. 1. Research flow chart.

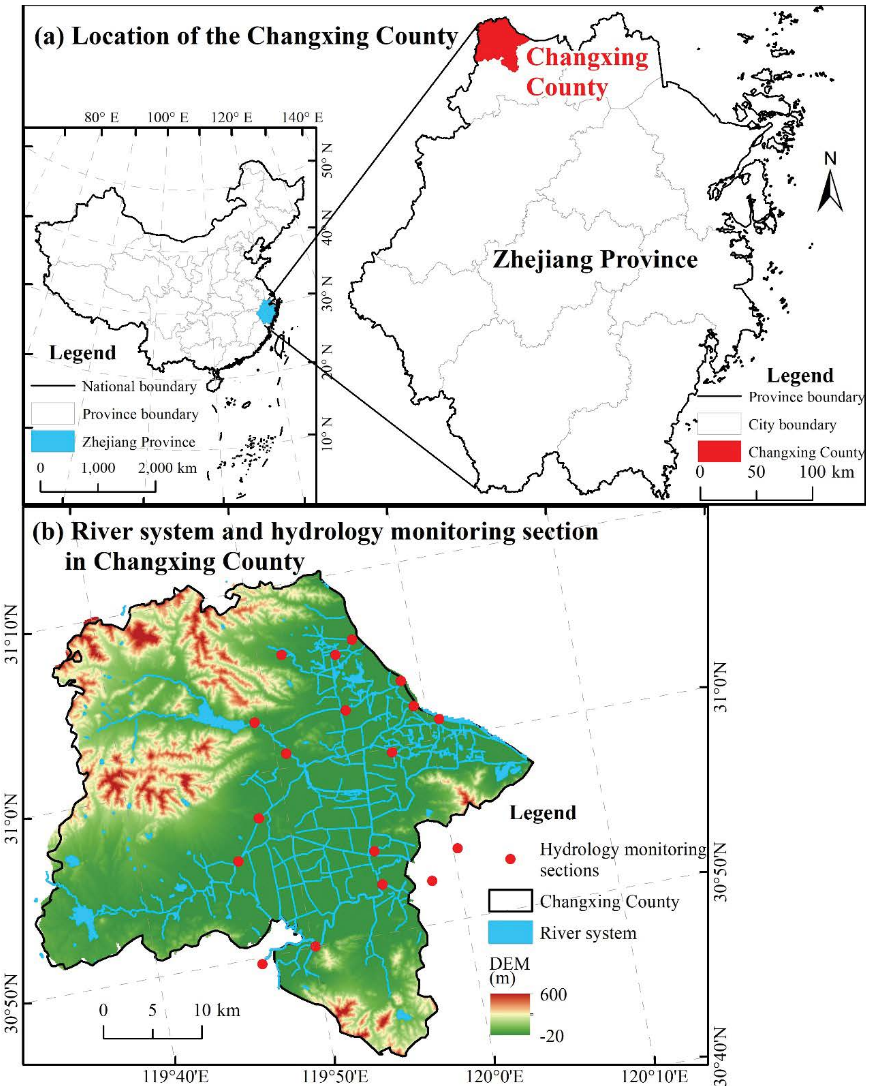

Fig. 2. Location of the study area.

Table 1
Data of various indicators of WECC in Changxing County from 2010 to 2018 and in different water periods in 2018

Indicator	Unit	Year									Water period		
		2010	2011	2012	2013	2014	2015	2016	2017	2018	Wet	Flat	Dry
D_1	Per inhabitant (km^2)	436	438	438	439	441	440	442	444	445	445	445	445
D_2	Billion yuan (km^2)	0.198	0.234	0.259	0.285	0.307	0.324	0.349	0.387	0.426	0.142	0.142	0.142
D_3	Ten thousand yuan (mu)	24.19	21.64	15.13	19.55	22.23	23.68	26.44	28.96	32.53	10.84	10.84	10.84
P_1	Tons	159.6	135.2	122.1	111.1	99.6	91.3	75.7	63.3	57.8	57.8	57.8	57.8
P_2	kg/hm^2	343	396	356	360	347	342	322	311	294	131	98	65
P_3	Tons/Ten thousands yuan	5.12	5.90	3.85	2.86	2.01	1.83	1.68	1.69	1.69	1.69	1.69	1.69
S_0	%	100	100	100	100	100	94.4	100	100	83.3	100	100	83.3
S_1	%	22.5	41.1	19.6	75.2	53.8	27.4	17.2	46.3	25.8	17.2	27.4	46.6
S_2	%	37.5	37.1	36.5	35.8	35.1	34.4	33.7	33.2	32.5	26.8	26.5	24.5
S_3	%	12.9	12.8	12.6	12.4	12.4	12.3	12.1	12.0	11.8	8.2	8.1	9.6
S_4	%	51.3	50.9	50.5	50.1	49.5	49.1	48.6	48.2	47.7	47.7	47.7	47.7
R_1	%	0.454	0.780	0.323	0.782	0.703	0.800	0.546	0.547	0.726	0.726	0.726	0.726
R_2	People	4	5	5	5	6	6	6	7	7	7	7	7
R_3	%	85.5	73.5	79.9	83.2	83.1	83.5	83.9	84.2	84.6	84.6	84.6	84.6
R_4	%	80.9	80.0	88.5	89.5	89.5	91.1	91.7	95.2	96.0	96.0	96.0	96.0
R_5	%	25	29	32	39	41	43	45	48	51	51	51	51
E_1	Yuan/Tons	41	29	43	61	78	89	73	76	133	133	133	133
E_2	Ten thousands yuan/Tons	129	88	105	141	158	172	209	261	347	347	347	347
E_3	Yuan/Tons	2.20	1.72	1.94	2.82	3.3	4.66	2.56	1.96	2.02	2.02	2.02	2.02
E_4	Yuan/Tons	1.01	0.78	0.87	1.25	1.57	1.09	1.19	0.91	0.95	0.95	0.95	0.95

2.3. Index system construction model

2.3.1. DPSRE model

Considering the socio-economic development and water environment, five subsystems of DPSRE framework are presented, including driving force, pressure, state, response and economic benefit. Economic benefit is the measure of the direct benefit of the water environment system [24], which reflects the economic value of the water environment to realize regional high-quality green development fully use of its own carrying capacity. Pressure illustrates the impact of human and social activities on the environment. State of the environment refers to the state and changes in the environment under the influence of human factors. Response describes the repairs and remedies that human society has taken on the destruction of the environment [25]. The DPSRE framework model distinguishes more steps and provides better insight into regional water environment economic benefits, which are the key factors for supporting sewage permit allocation technology in the study area. For example, population growth or socio-economic development, as the driving force of the water environment, puts different and variable pressure on the environment, resulting in changes in the state of the water environment, such as depletion of water resources and degradation of water environmental quality. Then, because of these changes, measures are taken to improve the quality of the water environment. Finally, by strengthening the response of each step, increased economic benefits of the water environment. Fig. 3 presents the details.

2.3.2. Evaluation index system of WECC

The WECC is influenced and restricted by various factors such as the water resources, water environment, water ecology, society and economy [10,26]. To establish the WECC evaluation index system, it is necessary to consider key indicators affecting WECC within the human-water environment systems, including the population, socio-economic factors, water resources, water environment and water ecology. Furthermore, the selected indicators are in accordance with established principles of accessibility, independence, relevance, dynamicity and quantifiability. The frequency analysis and expert consultation method in this study are used to screen indicators. As a result, a total of 20 indicators are selected to establish evaluation index system of WECC based on DPSRE method (Fig. 4).

2.3.3. One-vote veto mechanism of WECC

One-vote veto evaluation model is an effective environmental governance tool of government in China [27,28]. Taihu Lake is one of the most severely eutrophic freshwater lakes in China [29]. In order to achieve the clear water into the lake and the water quality of both control section and functional zone reached the target. In this study, the indicator of water quality compliance rate of regional exit section (S_0) was set as a key indicator, that is, when evaluating the WECC, take the key indicators one-vote veto mechanism, that is, if the indicator of S_0 did not reach 100%, the WECC of the area is directly judged to be overloaded.

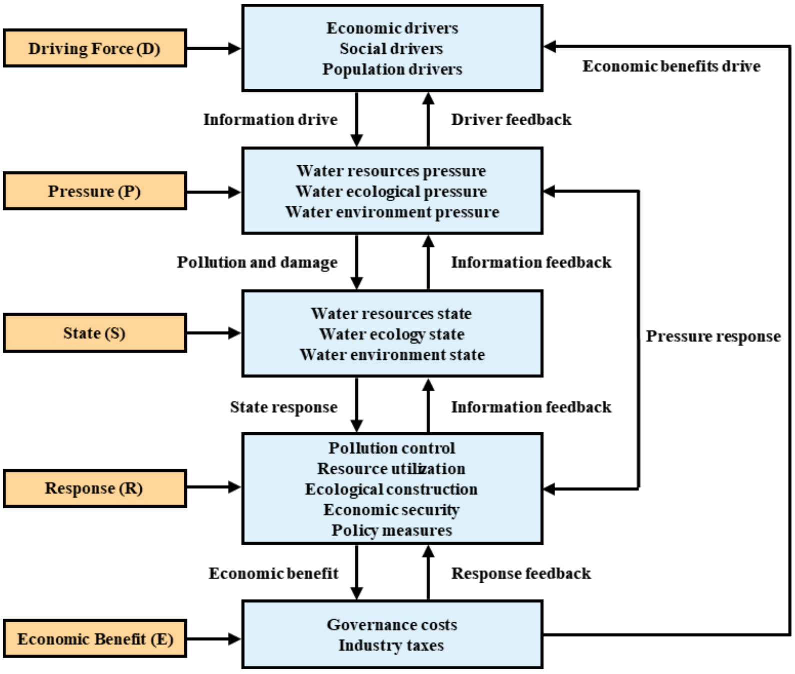

Fig. 3. DPSRE framework to assess regional WECC.

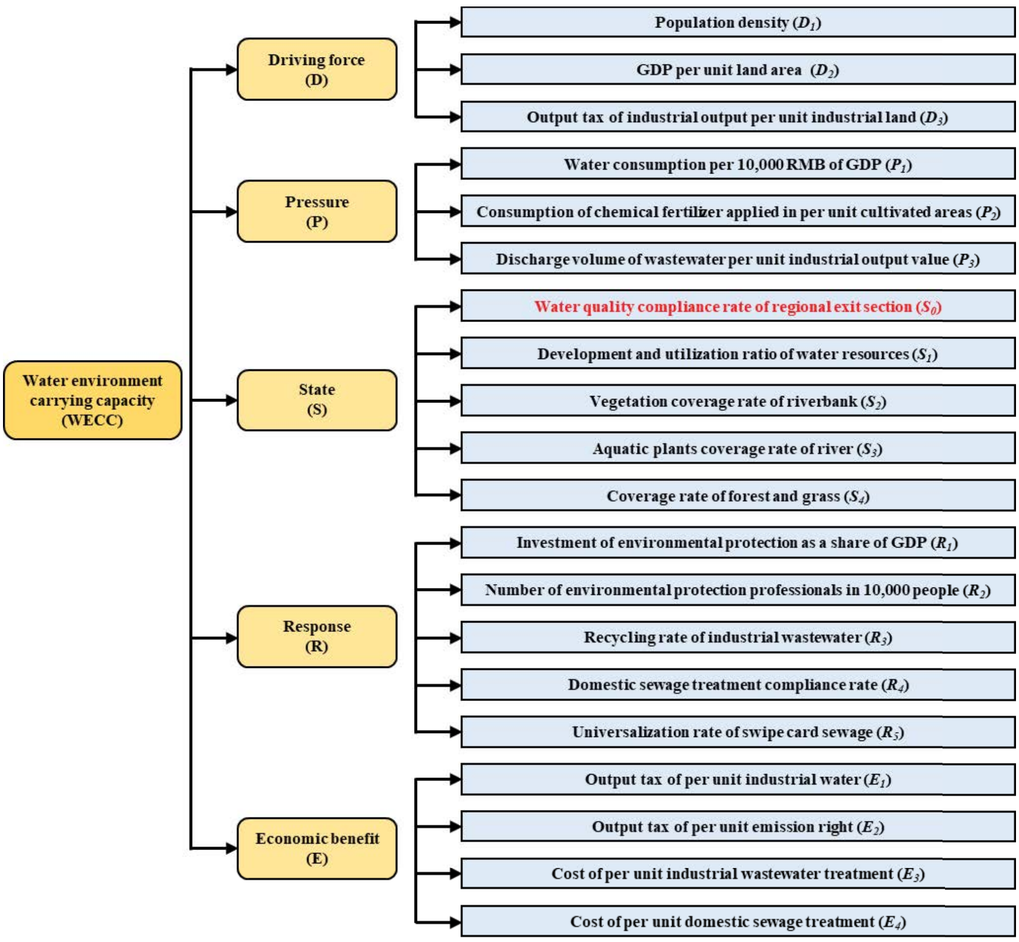

Fig. 4. Map of the WECC evaluation indicator system (S_0 is the key indicator).

2.4. Evaluation model of WECC

2.4.1. Determination of weights of the indicators

This study used AHP to determine the weight of indicators. AHP was proposed by Thomas L. Saaty in 1970s [30]. It is a structured multi-attribute decision method. The key steps to calculate the weight are as follows [31,32]: (1) divide complex problems into a hierarchical tree structure (usually object hierarchy, rule hierarchy and index hierarchy) according to the relationships between the various factors, each element is pair-wise compared in the same hierarchy, and the corresponding level is confirmed by assigning a numerical value (Table 2), and then form a judgment matrix. (2) Calculate the maximum eigenvector of the judgment matrix (λ_{max}). (3) The random consistency ratio (CR) of the judgment matrix is tested to obtain the weight. The CR is calculated by Eqs. (1) and (2), respectively. If CR < 0.1, the judgment matrix is considered to have satisfactory consistency.

$$\mathrm{CI} = \frac{(\lambda_{\max} - n)}{(n-1)} \tag{1}$$

$$\mathrm{CR} = \frac{\mathrm{CI}}{\mathrm{RI}} \tag{2}$$

where CI is the consistency index, n is the order of judgment matrix, RI is the random consistency index, and the value of RI is shown in Table 3.

2.4.2. Normalization of sample index value

The data of different indicators cannot be compared directly, and there are positive indicators and negative indicators, in order to calculate WECC index, the extreme standard method was used to standardize each indicator [33]. Eqs. (1) and (2) were used to normalize the data for the positive and negative indexes, respectively.

$$V_i = \begin{cases} 0 & b_i \le B_{i\min} \\ \dfrac{b_i - B_{i\min}}{B_{i\max} - B_{i\min}} & B_{i\min} < b_i < B_{i\max} \\ 1 & b_i \ge B_{i\max} \end{cases} \tag{3}$$

$$V_i = \begin{cases} 1 & b_i \le B_{i\min} \\ \dfrac{B_{i\max} - b_i}{B_{i\max} - B_{i\min}} & B_{i\min} < b_i < B_{i\max} \\ 0 & b_i \ge B_{i\max} \end{cases} \tag{4}$$

where b_i is the initial value of the indicator, V_i is the standard value of the ith index, $B_{i\max}$ and $B_{i\min}$ are the interval maximum and minimum values of the ith index respectively. The indicator standard for WECC is shown in Table 4.

2.4.3. Weighted summation method

The evaluation value of WECC was defined as:

$$S_{\mathrm{WECC}} = \sum_{i=1}^{m} S_i \omega_i \tag{5}$$

$$S_i = \sum_{j=1}^{n} Y_{ij} \theta_{ij} \tag{6}$$

where S_{WECC} is the evaluation value of WECC, S_i is the evaluation value of subsystem, ω_i is the weight of the ith subsystem, θ_{ij} is the weight of the jth index for ith subsystem, Y_{ij} is the normalization value of the jth index in the ith subsystem, m is the number of subsystems, n is the number of indexes in ith subsystems. The WECC states can be classified into three groups, shown in Table 5.

Table 3
Value of RI

n	RI
1	0
2	0
3	0.58
4	0.90
5	1.12
6	1.24
7	1.32
8	1.41
9	1.45
10	1.49

Table 2
Scale and its definition

Intensity of importance	Definition
1	Equal importance between the two elements
3	Weak importance of one element compared to the other
5	Essential importance of one element compared to the other
7	Very strong importance of one element compared to the other
9	Extreme importance of one element compared to the other
2, 4, 6, 8	Intermediate values between the two adjacent judgments
Reciprocals	If element *i* has one of the above numbers assigned to it when compared with element *j*, then *j* has the reciprocal value when compared with *i*

Table 4
Indicator standard for WECC

Subsystems	Indicators	Unit	Attributes	Grades		
				I	II	III
D	D_1	Per inhabitant (km^2)	Negative	≤200	200~1,000	≥1,000
	D_2	Billion yuan (km^2)	Positive	≥0.5	0~0.5	=0
	D_3	Ten thousand yuan (mu)	Positive	≥30	5~30	≤5
P	P_1	Tons	Negative	≤50	50~200	≥200
	P_2	kg/hm^2	Negative	≤225	225~500	≥500
	P_3	Tons/Ten thousands yuan	Negative	≤1	1~10	≥10
S	S_0	%	Positive	=100	0~100	=0
	S_1	%	Negative	≤10	10~100	≥100
	S_2	%	Positive	=1	0~1	=0
	S_3	%	Positive or negative	=0.3	0~0.3(+) 0.3~1(–)	=0 =1
	S_4	%	Positive	≥60	18~60	18≤
R	R_1	%	Positive	≥1	0~1	=0
	R_2	People	Positive	≥10	0~10	=0
	R_3	%	Positive	=100	20~100	≤20
	R_4	%	Positive	=100	50~100	≤50
	R_5	%	Positive	100	0~100	0
E	E_1	Yuan/Tons	Positive	≥100	20~100	≤20
	E_2	Ten thousands yuan/Tons	Positive	≥300	20~300	≤20
	E_3	Yuan/Tons	Negative	≤1.5	1.5~30	≥30
	E_4	Yuan/Tons	Negative	≤0.5	0.5~2	≥2

Table 5
Classification of WECC

Carrying status	WECC index values
Overload	0–0.5
Critical overload	0.5–0.7
Loadable	0.7–1

3. Results and discussion

3.1. Weight analysis of indicators and subsystems

As shown in Fig. 5a, the weights of driving force, pressure, state, response and economic benefit subsystems on WECC were 6.5%, 12.0%, 33.7%, 28.1%, and 19.7%, respectively. Weight of the state subsystem was the largest, indicated that the state subsystem is the most important impacting factor of the water environment in Changxing County. The weight of driving force subsystem was the lowest. It reflected that managers should pay more attention to improving the weight of driving force subsystem to reduce the impact of state on WECC. Shown in Fig. 5b, the top 5 indicators with the greatest impact on WECC are development and utilization ratio of water resources (S_1), domestic sewage treatment compliance rate (R_4), output tax of per unit emission right (E_2), vegetation coverage rate of riverbank (S_2), aquatic plants coverage rate of river (S_3). The indicator of S_1 was the most important indicator, the weight of which was 14.3%. The indicator of R_4 reflected the impact of domestic sewage on WECC. The weight of the indicator was 11.6%. The indicator of E_2 reflected the economic benefit of emission right, the weight of which was 9.2%. The indicator of S_2, S_3 reflected the impact of river water ecology on WECC. The weights of the two indicators were 7.6%. The indicator of population density (D_1) had the lowest influence weight. The weight of it was 1.3%. It reflected the low and stable population density and made little contribution to the improvement of WECC.

3.2. Results of comprehensive evaluation of WECC

The index of WECC in Changxing County is on the fluctuation rise (Fig. 6), from 0.57 in 2010 (critical overload in 2010–2014, overload in 2015 and 2018, loadable in 2017) to 0.71 in 2016 (loadable in 2016). From 2010 to 2016, the index value of WECC increased by 24.6% compared to that of 2010.

The evaluation value of each subsystem presented different degree of growth, except state subsystem (Fig. 7). Compared with the evaluation value in 2010, the evaluation value in 2018 of driving force, pressure, response, economic benefit subsystem increased by 0.27, 0.37, 0.21, and 0.50, respectively. The added value of economic benefit subsystem was the largest, indicating that it increased WECC significantly. The evaluation value of state subsystem was 0.65 in 2010 and it fell by 7.7% in 2018. It reflected the state of WECC was getting worse. The value of economic benefit subsystem was the largest in 10 y. Its evaluation value was

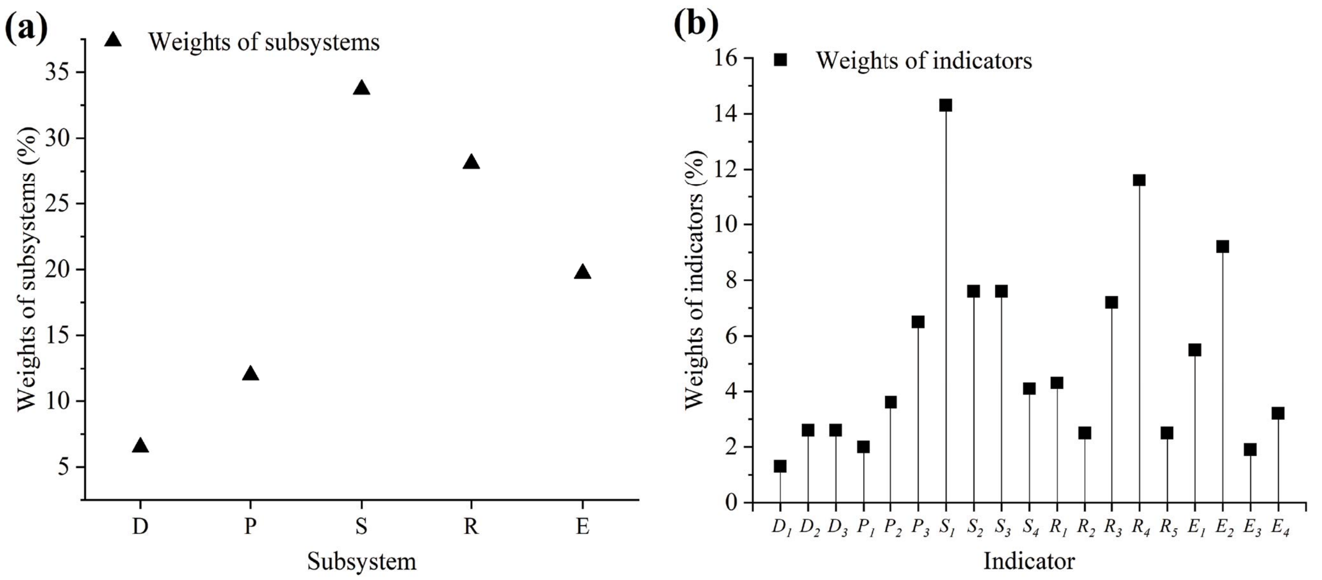

Fig. 5. Weights of subsystems (a) and indicators (b) (the details of indicators and subsystems Fig. 4).

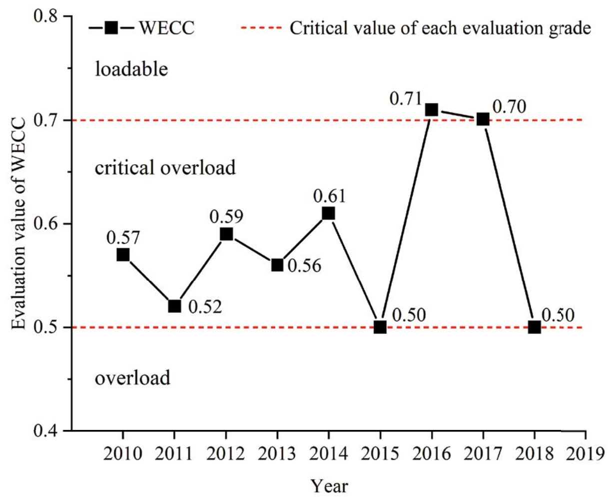

Fig. 6. Changing trend of WECC from 2010 to 2018.

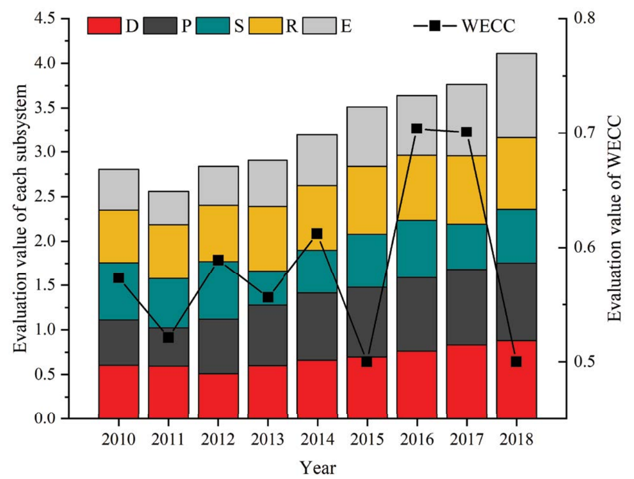

Fig. 7. The changing trend of WECC of each subsystem D (driving force), P (pressure), S (state), R (response), E (economic benefit) from 2010 to 2018.

0.95. It reflected the economic benefit was the most important influencing factor of WECC. In 2015 and 2018, WECC was overloaded. The major cause of the overload of WECC was that the water quality compliance rate of regional exit section did not reach 100%. The compliance rate of water quality was 94.4% in 2015 and 83.3% in 2018.

3.3. Influencing factors of WECC

In order to obtain the factors influencing the WECC, we analyzed the value of each index in driving force (D), pressure (P), state (S), response (R), and economic benefit (E) subsystems (Fig. 8).

In the driving force subsystem, the GDP per unit land area (D_2) is a key indicator of the driving force subsystem, and the evaluation index presented an upward trend year by year, with an increase of 115.2% in 2018 compared with 2010. The improvement of economic level will promote the development of the water environment. The carrying capacity evaluation index of output tax of industrial output per unit industrial land (D_3) is at a high level, showed a fluctuating change, and the evaluation value reached 1 in 2018, which indicates that the development of industry has contributed greatly to the improvement of the WECC.

In the pressure subsystem, water consumption per 10,000 RMB of GDP (P_1), consumption of chemical fertilizer applied in per unit cultivated areas (P_2) and discharge volume of wastewater per unit industrial output value (P_3) during 2010 to 2018 show an increasing trend. The value of P_1, P_2 and P_3 was 0.27, 0.57 and 0.54 in 2010 and they increased

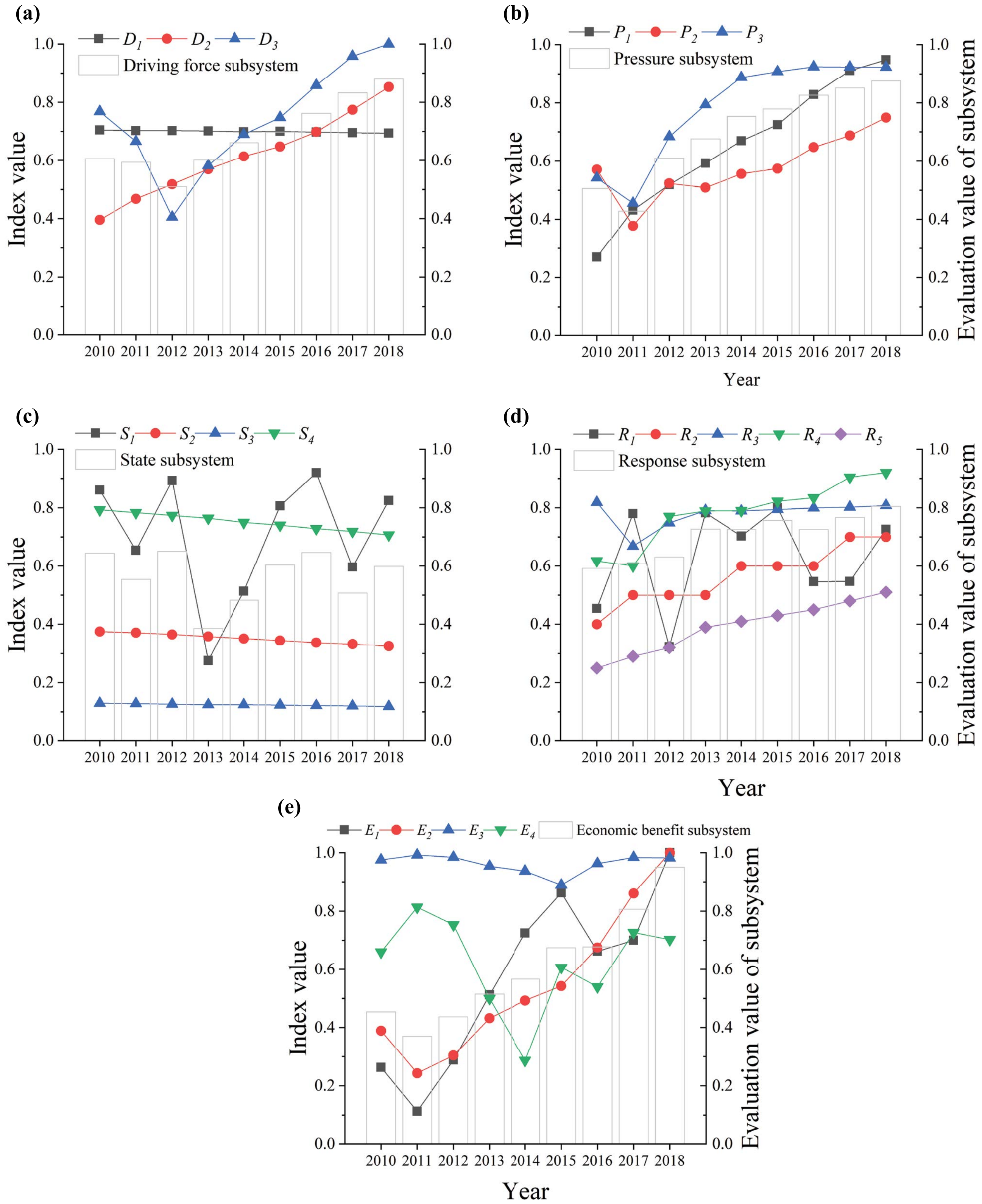

Fig. 8. The index evaluation value of driving force (a), pressure (b), state (c), response (d) and economic benefit (e) subsystems from 2010 to 2018 (the details of indicators Fig. 4).

252%, 31.2% and 70.3% in 2018 respectively, which indicate that the water environment pressure is decreasing.

In the state subsystem, the indexes of coverage rate of forest and grass (S_4), vegetation coverage rate of riverbank (S_2) and aquatic plants coverage rate of river (S_3) changed steadily, and the low evaluation value of indicators S_2 and S_3 was the main reason for the state subsystem to maintain a low level for many years. The two indicator's average evaluation values were 0.35 and 0.13 respectively. It suggested the deterioration in the water ecological of the river. Effective measures should be taken to prevent water body of river from deteriorating. In addition, Fig. 7 shows that the state subsystem caused the decline of WECC from 2012 to 2013. Fig. 8c shows which index caused the decrease of the value of the state subsystem. In Fig. 8c, the value of S_2, S_3 and S_4 remained basically the same in 9 y. The downward trend of the evaluation value of state subsystem was consistent with that of development and utilization ratio of water resources (S_1) from 2012 to 2013. The value of S_1 was 0.89 in 2012 and it decreased 69.2% in 2013. It reflected that the decrease of water resources was the real reason for the change of WECC in 2012–2013.

In the response subsystem, the three indicators of number of environmental protection professionals in 10,000 people (R_2), domestic sewage treatment compliance rate (R_4) and universalization rate of swipe card sewage (R_5) were the reasons for the increase of response subsystem. The three indexes added by 75%, 48.9% and 104%, respectively in 9 y. It indicated the government departments have responded positively to environmental issues.

According to Fig. 7, the improvement of WECC was attributed to the increase of the value of economic benefit subsystem. As shown in Fig. 8e, the value of output tax of per unit industrial water (E_1) and output tax of per unit emission right (E_2) increased significantly. It was 0.26, 0.39 in 2010 and it increased by 281%, 157% in 2018 respectively. The development of enterprises improved the economic benefit of water environment, which meant the indicator was the key to increase the WECC. Within 9 y, the value of cost of per unit industrial wastewater treatment (E_3) was relatively high, and the average value was 0.96. It had a great effect on improving WECC.

3.4. Analysis of WECC in different water periods

Fig. 9 displays the variation of the WECC of each subsystem in different water periods (wet, flat and dry) in 2018. It can be seen that the WECC was in a state of loadable during the wet and flat water period, overload in the dry water period. The major cause of the overload of WECC in dry water period was that the water quality compliance rate of regional exit section (S_0) did not reach 100%. The compliance rate of water quality 83.3% during dry water period. Furthermore, the driving force, response and economic benefit subsystem remained basically the same in 3 water periods. The evaluation value of pressure subsystem is higher in the dry period and lower in the wet period. From wet period to dry period, the value of state subsystem evaluation was decreased, which maintain a low level. The reason is mainly affected by the water resources, seasonal fertilization.

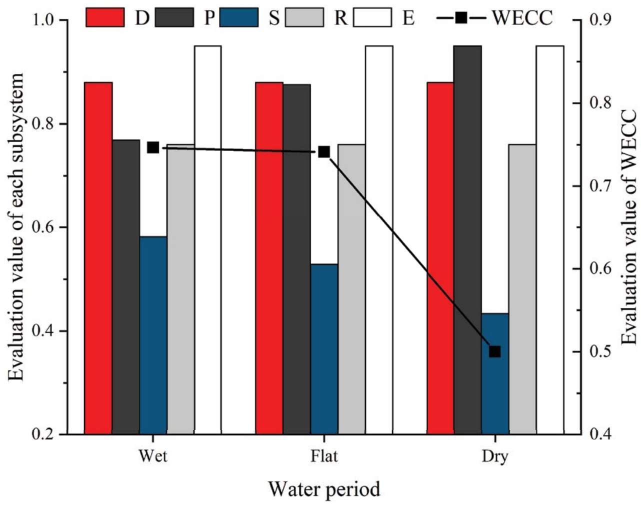

Fig. 9. The changing trend of WECC of each subsystem D (driving force), P (pressure), S (state), R (response), E (economic benefit) in different water periods in 2018.

4. Discussion

4.1. Analysis of the applicability of methods and the rationality of results

To study the inter-annual and seasonal variability of WECC, this paper explored a dynamic assessment method that combined one-vote veto mechanism and AHP model to evaluate indicators chosen under a DPSRE framework and used the weighted summation method to calculate WECC. In general, the evaluation process includes three main steps, that is, constructing the indicator system and determining the relevant standards, using the model for evaluation, and showing and analyzing the evaluation results. In the first step, because many key indicators mutually influence each other, the DPSRE model is chosen to construct the indicator system, which not only can systematically indicate the causal relationship of the indicators and contribute to further classifications of WECC but also avoids the randomness of other common methods [34]. Standards of each indicator are determined by references, which can scientifically distinguish carrying capacity level. The standards used in this paper were closely related to WECC and were previously used in the literature on the assessment of the water environment. In the second-step, one-vote veto mechanism is used to assess WECC due to the importance of water quality reached the target in plain river network area in East China, and the weight of indicators is calculated by an AHP. The AHP models solve quantification problems based on existing statistical data and experts in related fields with extensive knowledge and experience, and reflect more accurately the characteristics of water environment system restricted by complex factors. It can fully reflect the actual situation of the water environment system in Changxing County. In the third step, because large volumes of assessment data are hard to analyze, the weighted summation method is used to process the data and produce comprehensive assessment results, which have strong operability. On the whole, the method can reasonably quantify WECC and sensitively reflects the changing of values of indicators.

In the empirical process, the WECC of Changxing County showed a fluctuating increased trend from 2010 to 2018, and the WECC was loadable during the wet and flat water period, while overload in the dry water period in 2018. The first result is in line with the original intention and background of some relevant policies making, such as the Action Plan for Water Pollution Prevention and Control in 2015. Additionally, Chen [35] found that there was a fluctuating increased trend of the level of water resources carrying capacity in the Changxing County from 2010 to 2018, which was a completely identity conclusion to this study. Furthermore, in dry season in 2018, low water resources and high intensity of fertilization in the study area, resulting in water quality not reach the standard, the WECC was in a state of overload. Therefore, the assessment results are consistent with the actual situation, which indicates that the result is reasonable.

4.2. Policy suggestions

WECC system is composed of 'driving force-pressure-state-response-economic benefit' subsystems. Based on the results of previous analysis, the following suggestions need to be considered to improve WECC level:

- Rational utilization of water resources. According to the analysis of WECC assessment results, the impact of industrial, agricultural and domestic water on the WECC accounts for a large proportion. Therefore, in industry, managers should achieve industrial emissions reduction by adjusting pollution emissions standards and improving the reuse rate of industrial water. In agriculture, the government should be promoting water-saving irrigation facilities, constructing water storage facilities for agricultural seeding, which alleviates water shortage during dry periods. In life, managers should promote domestic water-saving by enhancing residents' awareness of water-saving, appropriately increasing water price and upgrading rural sewage treatment facilities.
- Paying more attention to river water ecological restoration. Strengthening river water ecological restoration is one of the most direct and effective measures to change the water environment carrying state, especially, vegetation coverage rate of riverbank (S_2) and aquatic plants coverage rate of river (S_3). Once the river water ecosystem is seriously degraded, there are extremely adverse effects on WECC. Thus, some management measures of river ecological restoration shall greatly be taken to improve carrying state of the water environment in the Changxing County.
- Prevention and control of agricultural non-point source pollution. In recent years, with the rapid development of heavy polluting agricultural cash crops in the Changxing County, such as tea and fruit industries, some powerful countermeasures urgently need to be formulated and implemented, including formulating fertilizer application standards, applying of slow-release fertilizer, developing ecological green agriculture and construction of buffer strips on both sides of the river bank, which aims to reduce the coefficient of pollutants into the river.

4.3. Scope and limitations of this study

This paper proposes a novel integrated model framework by coupling the DPSRE model, one-vote veto mechanism and AHP method, and uses the Changxing County as a case study to evaluate the WECC. DPSRE framework model provides a way to construct an index system. In addition, this evaluation method reflects the importance of the economic benefits of the water environment for WECC, and can effectively achieve water quality double compliance in plain river network area.

However, due to the complexity of the water environment system, there are still some deficiencies in this study. First, it is very difficult to collect some index data for many years. For example, as some data (involve river water ecology, industrial enterprises) obtained through field investigation and forecast, resulting in the deviation of the assessment results of the WECC. Second, the WECC status classification standards in this paper were established based on relevant research work. For researches on classification boundary of WECC, a unified standard has not yet been reached. In future research, we should optimize the data acquisition method and establish a database of WECC indicators. Furthermore, we should commit to improving the scoring criteria of the each index according to the actual situation, and gradually establish an objective and reasonable WECC grade standard.

5. Conclusions

In this study, DPSRE was developed from PSR framework model, and the application of the framework model provides a new method to construct the index system. It distinguishes more steps and provides better insight into the causal relationship between socio-economic development and water environment change under the background of high-quality green development in East China, supports sewage permit allocation technology in the study area. Furthermore, the one-vote veto mechanism of WECC proposed in this paper can fully reflect the importance of water quality reaches the target in river network areas. The research indicates that the DPSRE framework model is practical and can be used to study the WECC. The main results are summarized below.

- Changxing County's WECC showed a fluctuating growth trend from 2010 to 2018, the water environment was in critical overload status in 2010–2014, overload status in 2015, 2018, and loadable status in 2016, 2017. In addition, the WECC was in a status of loadable during the wet and flat water period, overload in the dry water period. It reflected that water environment in Changxing County was changing better and affected by water period.
- The influence weight of indicators and subsystems for WECC was different. The indicators of development and utilization ratio of water resources (S_1), domestic sewage treatment compliance rate (R_4), output tax of per unit emission right (E_2), vegetation coverage rate of riverbank (S_2), aquatic plants coverage rate of river (S_3) were top 5 indicators that affected WECC significantly. The state

subsystem' impact weight was higher than that of other subsystems. It suggested that the most important factor affecting WECC of Changxing County was state.

- The evaluation value of each subsystem presented different degree of growth, except state subsystem. Compared with the evaluation in 2010, the value in 2018 of driving force, pressure, response, economic benefit subsystem increased by 0.27, 0.37, 0.21, 0.50, respectively. The added value of economic benefit subsystem was largest, indicating that it increased WECC significantly. By analyzing the evaluation results, unstable water quality compliance rate, uneven distribution of water resources, ecological degradation of river and point and non-point source pollution were the main factors restricting the improvement of water environmental carrying capacity in Changxing County.
- From the results of analysis of the carrying capacity of various indicators, managers should pay more attention to highlighting the importance of rational utilization of water resources, promoting river water ecological restoration, and strengthening prevention and control of agricultural non-point source pollution to improve WECC.

Acknowledgments

This work was funded by the National Major Science and Technology Program for Water Pollution Control and Treatment of China (No. 2018ZX07208-009-03) and National Natural Science Foundation of China (NO. 71663039).

The Chinese Academy of Environmental Sciences had put forward suggestions and reference schemes for the evaluation method of water environmental carrying capacity and the construction of water environmental carrying capacity index system in river network areas. The Water Control Office of Changxing County, Zhejiang Province, and the Environmental Protection Bureau had provided basic data for this research.

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