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Sustainability assessment of water resource in Guangxi Xijiang river basin based on composite index method

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Abstract. Taken one of the rising national strategies of Xijiang river basin as the study area, we first established the sustainable utilization index system of water resources assessment. Then, the analytic hierarchy process was applied to calculate the index weights. And the composite index method was applied to evaluate the sustainability of water resources of the study area from 2010 to 2014. The results indicated that Nanning, Liuzhou, Guilin and Fangchenggang four cities had higher level of sustainability. Qinzhou and Chongzuo city were in the status of unsustainable. The Guangxi Xijiang river basin was in the status of sustainable level in the last five years. The degree of sustainable utilization fluctuated during the years, with the score went up to 43.26 from 2010 to 2013 and then declined to 39.75 at 2014.

Introduction

The problem of water resources, which China is confronted with, is one of the most important problems in the 21st century [1]. It has gradually become one of the important factors that affect the harmonious development of social economy and ecological environment. Therefore, the sustainable use of water resources is one of the hot topics in the current sustainable development researches.

The researches of sustainable utilization of water resources in western countries often focus on three scales, i.e., national, regional and river basin scale, with the perspective of reliability, resilience, vulnerability and fairness [2, 3]. Daniel established the framework of urban water resources analysis and proposed the index system of sustainable evaluation of water resources [4]. Loukas evaluated the potential of the surface and groundwater resources by applying the hydrological model and put forward the manage countermeasures of water resources [5].

The domestic researches often use comprehensive evaluation index system and water resources carrying capacity evaluation index system to measure the sustainable use of water resources [6, 7]. The ecological indicators, natural social indicators and economic indicators are mainly included in the system [8]. There are a variety of indicators and methods have been constructed to establish the sustainable evaluation of water resources, such as comprehensive score method, analytic hierarchy process, artificial neural network and fuzzy comprehensive evaluation method [9, 10].

After the national strategy-Development Planning of Zhujiang-Xijiang Economic Zone was implemented, the Xijiang river basin was developed as the principal axis of the economic zone, the main part of the economic development and occupied the significant strategic positions of the whole nation [11]. Although the Xijiang river basin is abundant in water resources, the spatial and

temporal distribution of precipitation is heterogeneous. And the water resource of Xijiang river basin has faced stress and threat from the accelerated and intensified development of economy, and resulted in increased demand for resources and water quality deterioration. Therefore, it is of great significance and urgency to explore the sustainable utilization of water resources of the Xijiang river basin, which is expected to provide scientific basis for the water management.

Study area

As the mainstream of the Pearl River, the Xijiang River is consisted of Hongshui river, Liu river, Qian river, Gui river, Yu river and Xun river and covers an area of 2.02×105 km^2 in the Guangxi Zhuang Autonomous Region, which accounted for 85.54% of the land area of Guangxi.

After the national strategy-Development Planning of Zhujiang-Xijiang Economic Zone was implemented in 2014, the Guangxi Xijiang river basin occupies an important strategic position in China Western Development.

In this study, the thirteen cities covered by the Guangxi Xijiang river basin were selected as the study area, including Nanning, Liuzhou, Guilin, Wuzhou, Guigang, Hezhou, Baise, Hechi, Yulin, Laibin, Chongzuo, Fangchenggang and Qinzhou. And the city was taken as the unit to obtain the evaluation index.

Materials and methods

Evaluation index. According to the requirement of sustainable utilization of water resources [12], the sustainable use index system of water resources in the study area was divided into three levels, i.e., objective layer, criterion layer and index layer.

Objective layer: The objective of the sustainable use of water resources is to comprehensively evaluate the capacity of sustainable use of water resources in the basin.

Criterion layer: The factors that affect the sustainable utilization of water resources. The evaluation criteria of sustainable utilization of water resources in the study area was established based on four aspects, that is current water resources, utilization degree of water resources, water resources and environment coordination situation and water resources allocation combined with status of water resources and socio – economic conditions.

Index layer: 1) Water resources conditions. It is one of the most important factors that determines the degree of water stress and supports the sustainable use of water resources of the study area. 2) Utilization degree of water resources. It reflects the development and conditions of water resources. From the perspective of sustainability, the water resources should be prevented from over developed. At the same time, in order to maintain social and economic development, it should have a certain degree of engineering capacity. 3) Ecological environment. The accelerated and intensified development of economy resulted in the water quality and environment deterioration. 4) Water resources allocation. It demonstrates the sustainable use of water resources definitely.

The following principles were considered when establishing an index system [13]: 1) Scientificity. The indexes were selected based on the scientific theory especially the concept and calculation method of the definition of sustainable development theory. 2) Comprehensiveness. The index should mirror the sustainable use of water resources from different aspects. The whole indicator system should systematically and comprehensively reflect the subsystems and their constituent elements of water resources utilization. 3) Operability. The selected index should have practical value and quantity research basis by combining the qualitative and quantitative methods.

Index weight and test. Calculate index weights by analytic hierarchy process. The reasonability of

index weight is related to the validity and scientificity of comprehensive assessment. According to the requirements of analytic hierarchy process, the indexed were scored by applying the 1-9 scale method from top to bottom by layer on the basis of the relative importance between every two factors. Then the judgment matrix was established to calculate the weight of each index.

By calculating the normalized eigenvectors of the matrix and performing a consistency check, more convincing relative value of a certain factor relative to the previous layer was obtained, which is the single order weight value. On this basis, with the weight of the previous layer of each factor, the relative importance weight of a certain factor relative to the previous level was calculated and that was the overall weight value.

Consistency check. By checking the consistency of the judgment matrix, we obtained the maximum eigenvalue of the matrix (Eq.1).

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n}\frac{\sum_{j=1}^{n} a_{ij} w_j}{w_i}. \tag{1}$$

The reasonability of the weight coefficient is based on the consistency check of the judgment matrix (Eq.2, Eq.3).

$$CI = (\lambda_{\max} - n) / (n-1). \tag{2}$$

$$CR = CI / RI. \tag{3}$$

Where n is the order of the judgment matrix, CR is the random consistency ratio of the judgment matrix, CI is the consistency index of the judgment matrix and RI is the mean random consistency index (Table 1).

Table 1 The value of *RI*

n	1	2	3	4	5	6	7	8	9
RI	0.00	0.00	0.52	0.89	1.12	1.25	1.35	1.42	1.46

When the random consistency ratio CR was less than 0.10, the judgment matrix was regarded as satisfying the consistency. Otherwise, the initial judgment matrix was considered as not satisfied. It is necessary to re-adjust the element scale value until it has a satisfied consistency.

Sustainability assessment. According to the weight value of the index system and unified standardized data, the composite index method is used to evaluate the sustainability of water resources in Guangxi Xijiang river basin (Eq. 4) [14].

$$C = \sum_{i=1}^{n} l_i U_i . \tag{4}$$

Where λ_i is weight of the index and the sum of the weight is 1, U_i is the data after dimensionless process, C is composite assess index.

Results and discussion

Assessment index system. The research is based on the water resource compound system. According to the characteristics of natural, social and water resources in the study area, nine indexed were selected to assess the sustainability of water resources of Guangxi Xijiang river basin, including per capita water resources, per capita urban water consumption and forest coverage and so on (Table 2).

Table 2 Evaluation index system and weight of sustainable water resource use in Guangxi Xijiang River basin

Criterion layer (C)	Weight (W_i)	Index layer	Weight (W_j)	Index weight (λ_i)
Water resources conditions	0.0830	S1 Average per capita water availability	0.0833	0.0692
		S2 Average water resources per hectare	0.1667	0.0138
Water resources development and utilization	0.2597	S3 Average per capita urban water consumption	0.0878	0.0228
		S4 Industrial water	0.4561	0.1184
		S5 Irrigation water	0.4561	0.1184
Ecological environment	0.3782	S6 Forest coverage	0.2595	0.0981
		S7 Treatment rate of domestic sewage	0.5993	0.2267
		S8 Waste water treatment ratio	0.1412	0.0534
Water resources allocation	0.2791	S9 Per capita GDP	1.0000	0.2791

The weights of both the criterion layer and the index layer were obtained based on the analytic hierarchy process and tested the consistency of the judgment matrix. The results indicated that *CR* equal to 0.0366 and random consistency ratio below 0.10, which manifested the satisfying consistency of the judgment matrix. That is to say, the generated judgment matrix is reasonable.

Comprehensive assessment. The comprehensive assessment results of individual city in Guangxi Xijiang river basin from 2010 to 2014 were obtained based on the composite index (Table 3).

Table 3 Comprehensive assessment results of the main cities in Guangxi Xijiang river basin from 2010 to 2014

City	2010	2011	2012	2013	2014
Nanning	55.38	55.65	63.49	66.62	61.99
Liuzhou	72.52	67.20	71.51	67.60	66.14
Guilin	64.02	61.60	63.91	71.15	60.63
Wuzhou	31.43	35.06	37.40	38.60	31.74
Fangchenggang	53.27	55.54	57.11	61.63	63.51
Qinzhou	16.90	23.88	21.03	27.40	27.77
Guigang	22.88	18.77	24.90	26.43	17.08
Yulin	33.05	33.99	36.21	37.51	29.74
Baise	34.57	36.17	35.33	40.79	41.74
Hezhou	24.71	23.01	26.94	27.29	21.19
Hechi	44.64	40.67	37.67	40.84	34.51
Laibing	36.68	37.04	37.74	37.23	32.03
Chongzuo	15.54	19.12	21.46	19.30	28.71

The comprehensive assessment results indicated that there four cities had higher level of sustainability of water resources during 2010 to 2014, i.e., Nanning, Liuzhou, Guilin and Fangchenggang, with the score of more than 50. This is because the better conditions of the water

resources, utilization degree of water resources, ecological environment and water resources allocation of the four cities.

Qinzhou and Congzuo had relative lower sustainability with the assessment results below 30 from 2010 to 2014, which indicated they were in the status of unsustainable. However, the sustainability of water resources presented ascending trend in general. This is attributed to the improvement of water resources conditions (average per capita water availability and average water resources per hectare) and water resource allocation (per capita GDP) within these years.

The comprehensive assessment results of Guangxi Xijiang river basin from 2010 to 2014 indicated that study area was in the status of sustainable level with the score of more than 30 in the five years (Table 4). The degree of sustainable utilization fluctuated during the years, presented ascending first and then descending trends. The level of sustainable utilization of water resources went up to 43.26 from 2010 to 2013 and then declined to 39.75 at 2014.

Table 4 The comprehensive assessment results of Guangxi Xijiang river basin

Year	2010	2011	2012	2013	2014
Assessment score	38.89	39.05	41.13	43.26	39.75

With the development of social-economic, the exploitation and utilization of water resources increased gradually, which resulted in the decline of average per capita water availability. In the meanwhile, the requirement of industrial water increased and also the discharge of wastewater. However, the wastewater treatment capacity hasn’t been improve accordingly, so the sustainable utilization of water resources presented descending trend since 2014.

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