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Coupling Coordination Evaluation of Water-Soil Resource Utilization and Eco-environment: The Case of Southeast Yunnan Province

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Abstract. Understanding past and current relationship between water-soil resources utilization and eco-environment is essential for predicting how these relationships may be affected by future human activities change. Combined with GIS technology and statistical analysis, based on the actual situation of water shortage, limited land resources and the prominent contradiction between the supply and demand of water-soil resources in the karst mountain area of southeast Yunnan province. This paper studies the coupling coordination relationship between the water-soil resources utilization and eco-environment in karst rocky region and evaluated the coupling coordination degree between the utilization of water-soil resources and the eco-environment by using the entropy weighting method and the system coupling theory. Results show that the model estimated the spatial and temporal variation between water-soil resources utilization and eco-environment parameters precisely. On this basis, the stress response mechanism of social and economic development and water-soil resources under the constraint of water-soil resources is further discussed by using impulse response function simulation, so as to provide theoretical and technical support for the sustainable development of regional water-soil resources.

1. Introduction

The utilization of water-soil resources is an important driving force of eco-environment change in karst mountain areas in southeast Yunnan. The effects of water-soil resources utilization on eco-environment change mainly include two aspects: firstly, the underlying surface of the earth surface is constantly changed, thus affecting the absorption and reflection of solar radiation; Secondly, it affects trace elements in the atmosphere, especially the emission and absorption of greenhouse gases. The effect of water-soil resource utilization on eco-environment factors is the basic aspect of the effect of regional water-soil resource utilization system on eco-environment. In this paper, hydrological and soil factors were selected as the research objects to explore the mechanism of action of water-soil resources utilization on eco-environmental factors in karst mountain areas in southeast Yunnan.

Regional water-soil resources and eco-environment is a complex system, a multi-level system internal coordination of the micro elements is an important performance of system, is also the important internal mechanism of system evolution, these microscopic irregular each factor will be fluctuations in the system of coordination mechanism under the catalysis in the same sequence parameter transformation and render the amplification effect. Therefore, research on regional water-soil resource utilization and eco-environment, the internal relations and the evolution pattern of needs from the perspective of system coupling and coordination, the coupling coordination model established between each subsystem, the changes within the system and the correlation of each factor which requires to carry out the regional water-soil resources coupled coordination analysis, establish regional water-soil resources and eco-environment in the integration of system coupling model, expounds the regional environmental protection, land resource utilization pattern and the coupling degree and coordination development state of water supply.

Therefore, the aims of the present study are; 1) to evaluate the coupling coordination degree between the utilization of water-soil resources and the eco-environment.2) to study the balance relationship between the supply and demand of water-soil resources.3) to study stress response mechanism of social and economic development and water-soil resources under the constraint of water-soil resources is further discussed by using impulse response function simulation,

2. Materials and methods

2.1 Study area

The present study focused on the southern Yunnan, which is one of the most important rocky desertification areas. It covered an area of 7.48 million km^2, the entire 30 counties in Yunnan province, China (Fig.1), situated at a latitude between 22°17′and 26°06′, and a longitude between 101°52′and 108°56′, representing the rocky desertification is the most concentrated area. The annual average temperature is 12.5°C, and average annual precipitation is 1500 mm. Total evaporation is 1200 mm per year, three times more than annual precipitations, and typical of the subtropical and tropical plateau monsoon climate. The soil parent material mainly consists of laterite and krasnozem.

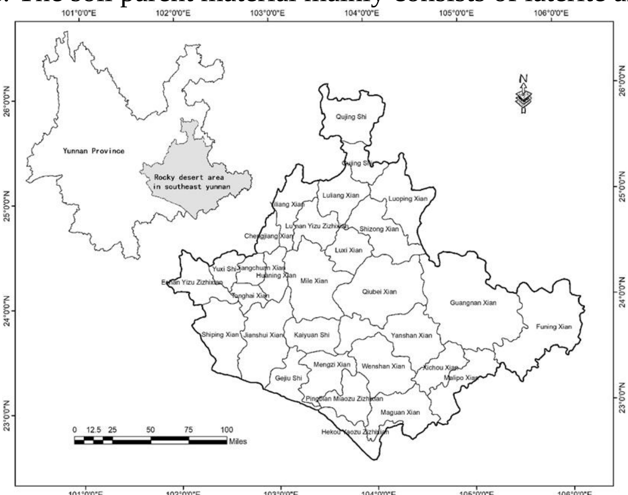

Fig. 1. Geographic location of the study area.

2.2 Data sources

In this study, we collected data which related to water resources were obtained from the bulletin of water resources of Yunnan province (2007-2016), the 13th five-year plan for water resources development of Yunnan province (2010-2015), the statistical network of Yunnan province and the website of water resources department.

Land resources related data from Yunnan statistical yearbook (2007-2016), Yunnan survey yearbook (2007-2016), the statistics bulletin of the national economy and social development in Yunnan province (2007-2016), the general land use planning in Yunnan province (2006-2020) and statistical network in Yunnan province and the department, planning department website, etc.

The relevant data of eco-environment were obtained from the bulletin of Yunnan environmental status (2007-2016), the 13th five-year plan of Yunnan eco-environment (2010-2016), the statistical website of Yunnan province and the website of the environmental department.

2.3 Research methods

2.3.1 Evaluation index system

According to this article defines the connotation of water-soil resource utilization and eco-environment, combined with utilization of southeast Yunnan water-soil resources and eco-environment vulnerability evaluation results, draw lessons from existing research results, build based on the subsystems of water resource utilization, land resource utilization and eco-environment subsystem of evaluation index system, the influence of water-soil resources utilization and the eco-environment of coupling coordination index screening, finally formed the characteristics of karst mountain area in southeast Yunnan evaluation index system.

The water resources utilization subsystem establishes the water resources utilization level measurement index system from the water resources supply and the water resources demand. The subsystem of land resource utilization establishes a land use level measurement index system from the three aspects of the connotation of land use, that is, the structure of land use, the degree of land use and the benefit of land use. The eco-environment subsystem, from the eco-environment connotation namely ecological conservation ability, eco-environment pressure, ecological governance level three aspects to establish the eco-environment level measurement index system.

In view of the authenticity, standardization and accessibility of data, this paper selects 31 indexes closely related to the coupling and coordination of water-soil resource utilization and eco-environment and strongly targeted from the statistical data officially released by the national bureau of statistics and the data released by authoritative institutions to construct the evaluation index system (table1). Each index is divided into two categories: positive index (+, the larger the better) and reverse index (-, the smaller the better) (Table 1).

2.3.2 Data standardization

Due to the different dimensions, orders of magnitude and properties of indicators, the original data need to be standardized to make the data comparable. The commonly used standardization methods include "extremum method", "averaging method", "efficiency coefficient method", "standardization treatment method", etc. In this paper, the method of range standardization is used to standardize the original data. When the larger the index value is, the more favorable the land use and eco-environment will be. When the smaller the index value is, the better the land use and eco-environment are, the negative index calculation formula is used to standardize the original data.

2.3.3 Index weight determination

The weight of the index is to distinguish the reflection of each index to different important degrees of the evaluation system. Whether the weight is scientific and reasonable will directly affect the accuracy of the evaluation results. Therefore, how to determine the weight coefficient is one of the core problems of the evaluation. So far, there are two main methods to determine weights: subjective weighting method and objective weighting method. Subjective weighting method is a method for decision analysts to weight the subjective importance of various indicators based on their own experience. The more common methods include Delphi method (expert scoring method), binomial coefficient method, AHP method (analytic hierarchy process), etc. Objective weighting method is a method to determine the weight simply by using the objective information of index attributes and the

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fixed calculation method, including entropy method, complex correlation coefficient method and principal component analysis method. Considering that subjective weighting method is easy to be affected by researchers' subjective judgment and their own knowledge system and other factors and has great limitations, this paper chooses objective weighting method to calculate the weight value of water-soil resource utilization and eco-environment system indicators. Entropy method and coefficient of variation method were used to assign weight respectively, and then the average value of the two methods was taken to determine the weight value of each evaluation index in this paper (Table 1).

Table 1. Coupling coordination evaluation index system and index weight

Subsystem	Indicator category	Indicator name	Indicator code	Indicator type	Indicator type
Land resource utilization subsystem	Land use structure	Cultivated land proportion	X1	+	0.0951
		Forest land proportion	X2	+	0.0963
		Construction land Proportion	X3	-	0.0905
		Water area proportion	X4	+	0.0879
	Land use degree	Land use degree comprehensive index	X5	+	0.0758
		Arable land per capita	X6	+	0.0746
		Cropping index	X7	+	0.0685
		Population density	X8	-	0.0729
		Land reclamation rate	X9	-	0.0763
	Land use efficiency	Per capita agricultural output value	X10	+	0.0634
		Land is average agricultural gross output value	X11	+	0.0635
		Per capita output of grain	X12	+	0.0671
		Per capita farmer's GDP	X13	+	0.0681
Water resource utilization subsystem	Water resources supply	Water resources gross	X14	+	0.1251
		Per capita water resources	X15	+	0.1063
		Water resources per unit area	X16	+	0.1005
		Matching coefficient of water-soil resources	X17	+	0.1279
		Utilization ratio of water resources	X18	+	0.1056
	Water resources demand	Proportion of water used for agriculture	X19	-	0.1226
		Industrial water ratio	X20	-	0.1034
		Domestic water ratio	X21	-	0.1015
		Ratio of ecological water consumption	X22	-	0.1071
Eco-environment subsystem	Ability of eco-environment conservation	Ecological water use rate	X23	+	0.1062
		Forest coverage rate	X24	+	0.1132
	eco-environment pressure	Karst area	X25	-	0.1011
		Area index of soil erosion	X26	-	0.0985
		Soil erosion area index	X27	-	0.1018
	Eco-environmental renovation	Desertification control area	X28	+	0.1217
		Soil erosion control area	X29	+	0.1037
		Converting farmland to forest	X30	+	0.1014
		Investment in ecological management	X31	+	0.1524

Standardization of all index data was defined based on the following formula:

$$Y = \{y_{ij}\} m \times n \tag{1}$$

Determine the weight of evaluation indicators:

$$y_{ij} = \frac{x'_{ij}}{\sum x'_{ij}} \tag{2}$$

Calculate the entropy value of the evaluation index:

$$e_j = \frac{-1}{\ln m} \times \sum y_{ij} \ln y_{ij} \quad (3)$$

Calculate the difference coefficient of evaluation indexes:

$$g_i = 1 - e_i \quad (4)$$

Determine the weight of evaluation indicators:

$$w_j = \frac{g_i}{\sum g_i} \quad (5)$$

2.3.4 Evaluation model and coupling coordination type

Evaluation model was defined based on the following formula:

Therefore, to build the coupling degree model, the first step is to build the function of the system.

U_i (I = 1,2,3) is the order parameter of the subsystem of "water resources, land resources and eco-environment" in the region, respectively reflecting the contribution of subsystem I to the overall system. X_{ij} (j = l, 2..., n) is the JTH index or influence factor of the ith order parameter, x_{ij} is its standardized efficacy function, and the following formula is used to calculate:

$$x'_{ij} = \begin{cases} \frac{x_{ij} - \min(x_{ij})}{\max(x_{ij}) - \min(x_{ij})}, & x_{ij}(\text{positive efficacy}) \\ \frac{\max(x_{ij}) - x_{ij}}{\max(x_{ij}) - \min(x_{ij})}, & x_{ij}(\text{negative efficacy}) \end{cases} \quad (6)$$

In the formula, Ui (I = 1,2,3) is the order parameter of the subsystem of "water resources, land resources and eco-environment" in the region, respectively reflecting the contribution of subsystem I to the total system. X_{ij} (j = l, 2..., n) is the JTH index or influence factor of the ith order parameter, x_{ij} is its standardized efficacy function, and the following formula is used to calculate:

$$U_i = \sum_{i=1}^{n} \lambda_{ij} \times x'_{ij} \quad (7)$$

$$\sum_{i=1}^{n} \lambda_{ij} = 1 \quad (8)$$

Based on the concept of capacity coupling and capacity coupling coefficient model in physics, the coupling degree model of the interaction among multiple systems was generalized, that is:

$$C = m \left\{ \frac{U_1 \times U_2 \ldots U_m}{\prod (U_i + U_j)} \right\}^{1/m} \quad (9)$$

$$C = 3 \left\{ \frac{U_1 \times U_2 \times U_3}{(U_1 + U_2 + U_3)^3} \right\}^{1/3} \quad (10)$$

Compared with the coupling degree model, the coordination degree model can better evaluate the coordination degree of mutual coupling among the three subsystems of regional water resources, land resources and eco-environment. The calculation formula is as follows:

$$D = (C \times T)^{1/2} \quad (11)$$

In the above equation, D is the system coupling coordination degree, T is the comprehensive coordination index of regional water resources, land resources and eco-environment, reflecting the overall coordination effect of regional water-soil resources ecosystem, which is calculated by the following formula:

$$T = \alpha \times U_1 + \beta \times U_2 + \gamma \times U_3 \quad (12)$$

The evaluation values of each subsystem of regional water resources and regional eco-environment, regional land resources and regional eco-environment, regional water resources and regional land resources are pairwise compared, and the comparison coefficient of subsystem contribution degree is calculated using the following formula:

$$\begin{cases} k_{water-eco} = \dfrac{U_1}{U_3} \\ k_{soil-eco} = \dfrac{U_2}{U_3} \\ k_{water-soil} = \dfrac{U_1}{U_2} \end{cases} \tag{13}$$

Comprehensive reference has been made to existing research results divided the coupling degree of regional water-soil resources utilization and eco-environment into 6 categories according to the degree of coupling degree (Table 2).

Table 2. Coupling degree classification

Coupling degree	Coupling range
No coupling	0.00<C≤0.50
Barely coupled	0.50<C≤0.60
Primary coupling	0.60<C≤0.70
Intermediate coupling	0.70<C≤0.80
good coupling	0.80<C≤0.90
High quality coupling	0.90<C≤1.00

Table 3. Classification of coupling coordination degree

Coordination degree		Coordination range	Coupling coordination type
Coordination	High coordination	0.90-1.00	Quality coordinated development type
		0.80-0.90	Well-coordinated development type
	Basic coordination	0.70-0.80	Intermediate coordinated development type
		0.60-0.70	Primary coordinated development type
		0.50-0.60	Primary coordinated development type
Imbalance	On the verge of disorder	0.40-0.50	Type of recession on the verge of dysfunction
		0.30-0.40	Mild disordered recession type
	Disorders of recession	0.20-0.30	Moderate abnormal recession type
		0.10-0.20	Severe imbalance recession type
		0.00-0.10	Extreme disorder recession type

3. Results and discussions

3.1 Analysis of time variance

It can be seen from (Table.4) and (Fig.2) that the comprehensive index of water-soil resources utilization in southeast Yunnan increased steadily from 2007 to 2016.Water resources increased from 0.3652 in 2007 to 0.7624 in 2016, indicating that with the development of social economy, the utilization degree of water-soil resources is constantly strengthened. From 2007 to 2016, the comprehensive index of eco-environment in southeast Yunnan decreased first and then increased gradually. From 0.5128 in 2007-2016 to 0.7966 in 2012, the increase rate exceeded the increase rate of the comprehensive land use index, which indicated that in the process of water-soil resources development, the eco-environment was damaged first, and then environmental protection was strengthened. From 2007 to 2016, the coupling degree of regional water-soil resources utilization and eco-environment was basically stable, around 0.9. The coupling and coordination degree of regional water-soil resources utilization and eco-environment is obviously changing. From 2007 to 2016, it experienced three processes of primary coupling, intermediate coupling and good coupling. In general, from 2014 to 2016, the utilization of water-soil resources and the development of eco-environment have been in sync, which indicates that the region pays more attention to the protection of eco-environment in the process of increasing land development and utilization.

Table 4. Coupling coordination results

Year	U_1	U_2	U_3	C	D	Coupling coordination type
2007	0.3652	0.5313	0.5128	0.8719	0.6184	Primary
2008	0.3461	0.5858	0.6004	0.8345	0.5964	Barely
2009	0.4428	0.5763	0.5729	0.9571	0.6972	Primary
2010	0.4672	0.6214	0.5642	0.9594	0.7121	Intermediate
2011	0.4812	0.6566	0.5867	0.9524	0.7221	Intermediate
2012	0.5128	0.6899	0.6618	0.9512	0.7499	Intermediate
2013	0.5237	0.7458	0.7346	0.9262	0.7570	Intermediate
2014	0.6048	0.7541	0.7258	0.9732	0.8112	Well
2015	0.7156	0.7743	0.7827	0.9953	0.8662	Well
2016	0.7624	0.7894	0.7966	0.9989	0.8838	Primary

3.2 Analysis of temporal variance

According to table 5, the southeast Yunnan 30 counties (cities and districts) relationship between the water-soil resource utilization and eco-environment can be roughly divided into two categories, one is land use evaluation index is greater than the comprehensive evaluation index of eco-environment, coupled with moderate development type coupling eco-environment of development lag and primary coupling eco-environment of development lag; Another type is the comprehensive evaluation index of land use is lower than the comprehensive evaluation index of eco-environment.

Table 5 Coupling coordination results of water-land resource utilization and eco-environment

Region	U_1	U_2	U_3	C	D	Coupling coordination type
Yi lang	0.5542	0.5768	0.6128	0.9949	0.7585	intermediate
Shi lin	0.4562	0.5858	0.6004	0.9562	0.7075	intermediate
Qi lin	0.5123	0.5763	0.5729	0.9914	0.7378	intermediate
Lu liang	0.5142	0.6214	0.5642	0.9822	0.7394	intermediate
Shi zong	0.5004	0.6566	0.4867	0.9453	0.6997	primary
Luo ping	0.4985	0.6458	0.4618	0.9387	0.6868	primary
Zhan yi	0.6815	0.6329	0.6346	0.9965	0.8032	good
Hong ta	0.7102	0.6645	0.7258	0.9958	0.8333	good
Jiang chuan	0.7108	0.7206	0.6841	0.9986	0.8385	good
Cheng jiang	0.6948	0.6245	0.6542	0.9943	0.8064	good
Tong hai	0.7123	0.5313	0.6128	0.9579	0.7536	intermediate
Hua ning	0.6754	0.5858	0.6004	0.9884	0.7786	intermediate
E shan	0.6918	0.5763	0.5729	0.9768	0.7652	intermediate
Mengzi	0.7043	0.6214	0.6642	0.9922	0.8081	good
Ge jiu	0.6142	0.6566	0.6867	0.9937	0.8027	good
Kai yuan	0.5741	0.6899	0.6618	0.9819	0.7867	intermediate
Ping bian	0.6815	0.7458	0.6451	0.9893	0.8222	good
Jian shui	0.7102	0.6129	0.5643	0.9730	0.7717	intermediate
Shi ping	0.6102	0.5847	0.5743	0.9981	0.7664	intermediate
Mi le	0.6674	0.6014	0.6057	0.9932	0.7851	intermediate
Lu xi	0.5324	0.5313	0.6128	0.9865	0.7375	intermediate
He kou	0.6781	0.5942	0.6004	0.9891	0.7815	intermediate
Wen shan	0.4428	0.4213	0.4431	0.9983	0.6590	primary
Yan shan	0.4672	0.3985	0.4685	0.9833	0.6557	primary
Xi chou	0.3924	0.4026	0.4154	0.9984	0.6342	primary
Ma lipo	0.3678	0.4018	0.4302	0.9878	0.6247	primary
Ma guan	0.3345	0.4985	0.3376	0.8979	0.5609	reluctantly
Qiu bei	0.3651	0.4715	0.4175	0.9679	0.6258	primary
Guang nan	0.2964	0.4457	0.3348	0.9143	0.5478	reluctantly
Fu ning	0.3561	0.5568	0.3756	0.8835	0.5790	reluctantly

Introduced by analysis results, the karst mountain area of water-soil resources utilization and eco-environment protection, there are a lot of coupling coordination between space need to further coordinate the relationship between water-soil resources and the eco-environment, the use of water-soil resources structure, the development and utilization of consistent patterns and the conditions of eco-environment protection, realize the benign evolution of regional water-soil resources ecosystem, eventually reach high quality coordinated development type.

4. Conclusion

In this study, the ecological and environmental vulnerability assessment results of 30 karst counties in southeast Yunnan showed that eco-environment vulnerability of karst region reflects the comprehensive effect of special natural factors and human activities. Due to the many and complex factors affecting the eco-environment and the difficulty of karst vulnerability environment governance, the evaluation results were comprehensively analysed and combined with the principle of regional conjugation to summarize the characteristics of karst rocky desertification eco-environment vulnerability areas in southeast Yunnan, which were mainly reflected in many aspects.

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