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Study on the coupling relationship between water environment and social economy in Ganjiang River basin

Bofu Zheng[a,b], Junyan Zhao[a,b], Da You[a,b,*]

[a]*College of Resources Environmental & Chemical Engineering, Nanchang University, Nanchang, China, emails: youdahn@163.com (D. You), bfzhen@ncu.edu.cn (B. Zheng), zhaojunyan@126.com (J. Zhao)*
[b]*Key Laboratory of Poyang Lake Environment and Resource Utilization, Ministry of Education, Nanchang, China*

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ABSTRACT

Investigating the coupling relationship between water environment and social economy is the hot issue in the sustainability study of river basin. Ganjiang River is the largest tributary of Poyang Lake watershed in China. Based on the social economic and water environment status quo in Ganjiang River basin from 1999 to 2016, this research builds the coupling coordinate model, and uses this model to analyze the coupling degree and coordinate degree between the social economic development and the water environmental quality by constructing evaluate formulate, comprehensive utilization of principal component analysis method and coupling model. The results indicate that for the time node of 2006, the period from 1999 to 2006 is the social economic lag phase and the period from 2007 to 2016 is the water environment lag phase; in the Ganjiang River basin, the coupling degree and the coordinate degree between social economy and water environment are not ideal from 1999 to 2016. If this basin continues the existing development speed, the pressure of water environment brought by the social and economic development will become very huge in the next years.

Keywords: River basin; Water environment; Social economy; Coupling relationship

1. Introduction

Gangjiang is the main river running through the north and the south in Jiangxi province, whose water environment quality is related closely to the economic and social development of Poyang Lake Basin. The long-term industrial structure "mining and fruit industry upstream, agriculture and chemical industry in the midstream, livestock breeding and service industry downstream" result in the contradiction between the economic development and the water environment quality of Ganjiang River basin. Building an indicator evaluation system of basin water environment–social–economic complex system, and analyzing the coupling relation between socioeconomic and water environment in this basin is of far-reaching significance that to expose the coordinated control mechanism between water environment and social economy of Ganjiang River basin, and to propose a new model for the sustainable development of river basin.

At present, the coupling coordination mechanism of water environment and social economic development mostly take administrative area as research dimension [1–3], the research scale that watershed and other natural regions in coupling degree and evolution mechanism of water environment and social economy is rare. As for research methods, the Environmental Kuznets Curve raised by American economist Grossman and Krueger in the 1990's has been the most widely used in the qualitative description of the coupling relationship between the internal environment and the economy. There are a lot of quantitative research models such as PSR model [4–6], coupling relation degree model

* Corresponding author.

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[5,7,8], system dynamics model [9–13], etc. Among various methods, the coupling coordination model is an evaluation model derived from the coupling coefficient of Physics and Synergism Theory. The complexity of the system and the volatility of economic development and environmental change are well avoided in virtue of this model's simplification, scientificalness, intuitiveness and so on [14,15]. It can be applied to different research areas, and it is the most widely used evaluation tool to describe the coupling mechanism between the internal environment and social economy of the system [12,15]. The study is based on the existing research, using coupling coordination measure model to make a systematic evaluation of Ganjiang River basin water environment and social economy coupling mechanism.

Ganjiang is the longest river in Poyang lake basin, whose length is 1,200 km and can be divided into upstream, middle and lower reaches through the boundary between Xiajiang hydrological station and Dongbei hydrological station. Ganjiang River basin including Ganzhou, Ji'an, Xinyu, Pingxiang, Yichun, Nanchang and other regions a total of 44 counties (cities, districts), of which the total area is 81,000 and 600 km^2 and accounting for 49.6% of the land area of Jiangxi Province.

2. Methodology

2.1. Coupling coordination measure model

The coupling coordination measure model is one of the important tools to evaluate the coupling degree between the environmental system and the economic system and predict its future trend, which has a very important guiding significance for the establishment of effective coordination mechanism in the study area [16,17]. This model combines the degree and coordination of the integrated interaction between water environment system and social–economic system, which can summarize and comprehensively reflect the sustainable development of the water environment in the basin and have a higher stability [18–20].

The method of calculating the coupled coordination measure model is generally divided into two steps: first, mathematical statistical analysis method is used to translate index elements that reflect the environmental and economic into a complex macrosystem that can reflect the overall situation indicators. Second, according to the grading standards, the coupling degree and coordination degree analysis model is established to analyze the overall evaluation results for the degree of coupling between economic system and environmental system. The specific formula is as follows:

$$T = \alpha A(x) + \beta B(y) \quad (1)$$

$$C_{xy} = \left(A(x)+B(y)\right) / \sqrt{A(x)^2 + B(y)^2} \quad (2)$$

$$D = \sqrt{C \times T} \quad (3)$$

Among them, $A(x)$ and $B(y)$ represent the evaluation of social–economic subsystems and water environment subsystems, respectively; T is the index of comprehensive evaluation of social–economic development and water environment, and it represents the comprehensive level of sustainable development in the research area; α and β represent subsystem evaluation coefficient (normally, when $A(x)$ and $B(y)$ are equally important, $\alpha = \beta = 0.5$); C_{xy} is the index of coordinated development of water environment system and social economic system, indicating the degree of coordination between the two interactions; D is the coupling degree of the compound system in the basin and the degree of mutual coupling of the compound system.

Evaluation grades are shown in Table 1 [8] and Table 2 [15,21].

2.2. Principal component analysis method

The principal component analysis method transforms the number of interrelated indicators into a few statistical methods of comprehensive indicators through the dimension reduction, whose outstanding advantage is dimensionality analysis is able to use the typical minority factor instead of the overall effect, make full use of the original information and remove the correlation between multiple indicators and information overlap. This information covers more than 85% of the original index information, with objective, scientific, reliable and accurate evaluation characteristics.

Principal component analysis of the model:

$$\begin{cases} F_1 = a_{11}X_1 + a_{21}X_2 + \cdots a_{p1}X_p \\ F_2 = a_{12}X_1 + a_{22}X_2 + \cdots a_{p2}X_p \\ \cdots\cdots \\ F_p = a_{1p}X_1 + a_{2p}X_2 + \cdots a_{pp}X_p \end{cases} \quad (4)$$

The following conditions:

(1) The sum of squares of each principal component coefficient is 1:

$$a_{1i}^2 + a_{2i}^2 + \cdots a_{pi}^2 = 1 \quad (i = 1, 2, \cdots m) \quad (5)$$

(2) The main components are not related to each other before:

$$\mathrm{cov}(F_i, F_i) = 0 \quad (6)$$

(3) The variance of principal components decreases in turn:

$$\mathrm{Var}(F_1) \geq \mathrm{Var}(F_2) \geq \cdots \mathrm{Var}(F_p) \quad (7)$$

2.3. Data processing

The data processing method adopts the dimensionless standardization method, namely Z-score method:

$$\text{Forward indicator}: X_i = \frac{x_i - \bar{x}}{s} \quad (8)$$

Table 1
Hierarchies of coordinated development

	C_{xy}	$A(x)$, $B(y)$	Coupling coordination degree	Characteristic
1	$1.2 \leq C_{xy} < 1.414$	$A(x) > 0$, $B(y) > 0$, $A(x) \approx B(y)$	Level-well coordination	Social economy and ecological environment development approaching equilibrium, perfect
2	$1.0 \leq C_{xy} < 1.2$	$A(x) > 0$, $B(y) > 0$, $A(x) > B(y)$	Moderate coordination	Rate of social–economic development is higher than that of the ecological environment, fairly respectable
3	$0.8 \leq C_{xy} < 1.0$	$A(x) > 0$	Mild coordination	Rapid growth of social–economic development, the ecological environment to maintain its capacity within the short-term acceptable
4	$0.5 \leq C_{xy} < 0.8$	$A(x) > 0$	Mild disorders	Rapid social and economic growth, ecological environment remained within its carrying capacity
5	$0 \leq C_{xy} < 0.5$	$A(x)*B(y) < 0$	Moderate disorders	Social–economic development transformed from low speed to rapid growth, and the ecological environment barely kept within its carrying capacity
6	$-1.414 \leq C_{xy} < 0$	$A(x)*B(y) < 0$	Serious disorders	Social–economic development is transformed from low speed to rapid growth, and the ecological environment is deteriorating, with prominent contradictions between the two

Table 2
Displacement of the system coupling degree

D	Coupling degree
[0, 0.3]	Low-level coupling
[0.3, 0.5]	Antagonist
[0.5, 0.8]	Benign coupling
[0.8, 1]	High-level coupling

$$\text{Reverse indicator}: X_i = \frac{\bar{x} - x_i}{s} \tag{9}$$

Among them, x_i is the index value; $\bar{x}$ is the index mean; s is the mean square error.

2.4. Construction of index system

There are two target levels that water environment subsystem and social–economic subsystem to the index selection and system construction in evaluation of the coupling relationship between water environment and social–economic in Ganjiang River basin.

The water environment indicators of Ganjiang River basin are divided into two aspects: water resources load and water pollution load by the existing regional water environment economic evaluation, regional sustainable development assessment and other research, combined with statistical data on the water environment, a total of 13 indicators:

(1) Water load, including seven indicators of surface runoff, total amount of water, total amount of agricultural water, total amount of industrial water, total amount of domestic water, water consumption per 10,000 yuan of industrial added value and water consumption per 10,000 yuan of GDP;
(2) Water pollution load, including the total amount of waste water discharge, industrial waste water discharge, domestic sewage discharge, fertilizer application (pure), chemical oxygen demand emissions, NH_3-N emissions and other six indicators.

In order to fully reflect the evolution of the social and economic system in Ganjiang River basin, this study measures from the following three aspects mainly, a total of 16 indicators:

(1) *Social development level*: There are mainly the total population, urban population, rural population, population density, average annual income of urban residents, annual income of rural residents, urbanization rate, per capita GDP and other eight indicators;
(2) *Status of economic structure*: There are mainly the total GDP, the added value of the primary industry, the added value of the secondary industry and the added value of the tertiary industry four indicators.
(3) *Economic development scale*: There are mainly the industrial added value, the industrial added value as a share of GDP, the total grain output, the total output of meat and other four indicators.

3. Result analysis

3.1. Data standardization

Getting the related data of social and economic indicators of Ganjiang River basin according to the Statistical Yearbook of Jiangxi Province and other cities; Accessing to Ganjiang River basin water environment related index data according to Jiangxi Provincial Water Resources Bulletin. Then the data obtained are dimensionless normalized.

3.2. Calculation results

The principal component analysis of each index data of social economy subsystem was conducted with SPSS 19.0 software, and a principal component X_1 was extracted according to the eigenvalue and the variance contribution rate of the correlation coefficient matrix. The cumulative variance contribution rate of X1 is 95.02%, which is over 85%, so the original 16 indicators of the social–economic subsystem can represented by this new variable.

Similarly, four main components Y_1, Y_2, Y_3, Y_4 were extracted by the water environment subsystem. The cumulative variance contribution rate of these four components is 89.95%, so the original 13 index data can be represented by these four new variables.

The four new variables Y_1, Y_2, Y_3, Y_4 of the water environment subsystem are normalized according to the extracted principal components, and the water environment subsystem development level appraisal value can be derived. Then the coordination of water environment and socio-economic system in Ganjiang River basin can be calculated on the basis of the specific formulae (1)–(3).

3.3. Result analysis

3.3.1. Subsystem development level analysis

In Table 3, X and Y are the composite scores after the principal component analysis of the social economy subsystem and the water environment subsystem, respectively. The result shows that (Fig. 1): (1) from 1999 to 2006, the comprehensive social–economic values are always lower than the integrated value of water environment, which is a state of lagging economy. However, the degree of lag has been gradually reduced. (2) In 2006, the curve of the integrated social–economic value and the water environment integrated curve converge approximately at zero, which is at the synchronous stage of water environment and social economic development. The development of social economy reaches the maximum value of self-adjustment of water environment. (3) From 2006 to 2016, water environment is at a lagging stage of development. The mode of social–economic development has exceeded the maximum capacity of the water environment to adjust itself and the water environment is gradually deteriorating. But the economic status can provide some financial and scientific support for the improvement of water environment at this time, the reason for the fluctuation of the comprehensive value of water environment is the increase of investment in water environment management and the improvement of management level after 2009. (4) The overall social–economic values show an overall upward trend and the overall water environment values have generally declined which means the two were negatively related to the development status and did not show the evolution of coordinated development during this period.

Table 3
Coupling coordination degree of water environment and social economy system

Year	$A(x)$	$B(y)$	C_{xy}	Coordination degree	T	D	Coupling degree
1999	–1.3592	1.1931	–0.0918	Serious disorders	–0.0831	0.0873	Low-level coupling
2000	–1.1095	1.0797	–0.0192	Serious disorders	–0.0149	0.0169	Low-level coupling
2001	–1.0825	0.4911	–0.4975	Serious disorders	–0.2957	0.3836	Antagonist
2002	–0.9073	0.424	–0.4826	Serious disorders	–0.2417	0.3415	Antagonist
2003	–0.7623	0.2389	–0.6552	Serious disorders	–0.2617	0.4141	Antagonist
2004	–0.4404	0.1974	–0.5035	Serious disorders	–0.1215	0.2473	Low-level coupling
2005	–0.2017	0.1295	–0.3012	Serious disorders	–0.0361	0.1043	Low-level coupling
2006	–0.0126	0.0112	–0.0830	Serious disorders	–0.0007	0.0076	Low-level coupling
2007	0.3003	–0.1558	0.4271	Moderate disorders	0.0723	0.1757	Low-level coupling
2008	0.5871	–0.2951	0.4444	Moderate disorders	0.1460	0.2547	Low-level coupling
2009	0.8374	–0.3917	0.4821	Moderate disorders	0.2229	0.3278	Antagonist
2010	1.0214	–0.5328	0.4241	Moderate disorders	0.2443	0.3219	Antagonist
2011	1.4328	–0.7651	0.4111	Moderate disorders	0.3339	0.3705	Antagonist
2012	1.6967	–0.9813	0.3650	Moderate disorders	0.3577	0.3613	Antagonist
2013	1.7468	–0.8625	0.4539	Moderate disorders	0.4422	0.4480	Antagonist
2014	1.8156	–0.8136	0.5036	Mild disorders	0.5010	0.5023	Benign coupling
2015	1.8963	–0.7948	0.5357	Mild disorders	0.5508	0.5432	Benign coupling
2016	1.9632	–0.7652	0.5686	Mild disorders	0.5990	0.5836	Benign coupling

3.3.2. Watershed coupling coordination evaluation

The comprehensive development index *T*, the degree of coordination *C* and the degree of coupling *D* of the social–economic subsystem and the water environment subsystem in Ganjiang River basin are shown in Fig. 2.

According to Fig. 2 and Table 3:

(1) The comprehensive evaluation index *T* of the river basin showed a fluctuation increase, which means the overall status of the integrated system of social economy and water environment in Ganjiang River basin is getting better;

(2) From 1999 to 2012, basin coordination index *C* rose, the overall tended to be coordinated, the evolution of the law can be divided into two stages: From 1999 to 2006, the value of *C* declines, the subsystems are in an disharmful state and the degree of disharmony is gradually aggravated which means the drainage basin is a rough development mode of economic growth at the expense of the environment, resulting in the deterioration of the water environment and further curbing the development of the society and economy during this period. The system of sustainable development of the basin is in a state of recession and the degree of disharmony reached its peak in 2006; From 2006 to 2012, *C* value fluctuations increased, and the compound system is barely in a reconciling state. The water environment is characterized by "deterioration-restoration-deterioration-restoration", which is consistent with the changing trend of the water environment subsystem in Fig. 2. The level of social–economic development had been able to meet the related needs of improving water environment and helped to ease the deterioration of water environment. Although it is still in a state of reluctance, this development trend is conducive to maintaining the development of the entire system;

(3) The degree of coupling *D* reflects the orderliness of the water environment and social economy subsystems in the Ganjiang River basin, with an overall waveform change. The subsystems are in an orderly and interactive coupling state, but the coupling level did not surpass 0.5, and the imbalance between social–economic development and water environment evolution was still affecting each other during this period.

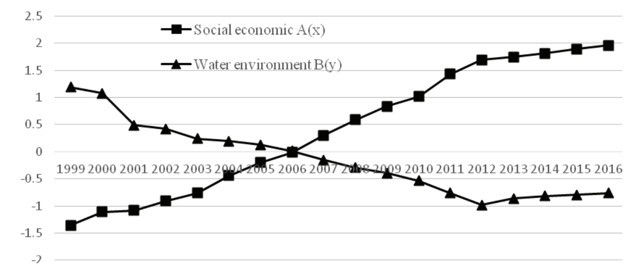

Fig. 1. Subsystem value change curve of Ganjiang river basin.

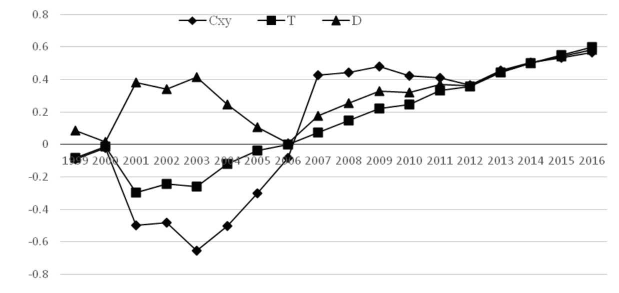

Fig. 2. Comprehensive evaluation index and coordination index, the index of the coupling change curve.

3.3.3. Comprehensive evaluation of Ganjiang River basin

In summary, from 1999 to 2006, social–economic and water environment were in an uncoordinated, low-level coupling and middle stage of economic development. *D* value and *C* value were almost zero, but the decrease of *D* value indicates that the system from disorder to disorder development. The water environment had not yet formed a strict dependence owing to the low level of economic development and the binding of water environment to socioeconomic was almost zero. The reason for the uncoordinated state of water environment and social economy lies in the fact that the degree of interaction with each other is at a low level and this state cannot form a serious mutual influence.

From 2001 to 2003, the complex system was in an uncoordinated antagonistic state, with fluctuation of *D* value and decreased of *C* value, the evolution of the system was relatively more orderly, and the degree of disharmony was greater, indicating that the social–economic development was more dependent on the water environment and the imbalance began to highlight. The water environment had became increasingly binding on society and economy, and the antagonistic coupling reflected the fact that the social economy can begin to provide the necessary elements for improving the water environment. However, due to the economic lag at this time, the contradictions among the subsystems were not obvious, and the water environment did not attract too much attention, so the mode of development had not changed. This stage is the best time to improve the water environment and realize the sustainable development of the system.

From 2007 to 2016, the system was in a state of reluctance to reconcile with a low level of coupling before 2009 and then into an interaction phase of antagonism and low-level coupling. The increase of *C* value indicated that the system has begun to take measures to alleviate the contradiction between social–economic development and the deteriorating water environment at the key point of its evolution. The increase of *T* value showed that the system starts to develop benignly, but the fluctuation of *D* value showed that water environmental improvement is still inadequate, and has not reached a benign coordination and symbiosis. Although the restriction of water environment on social and economic development had eased, the lagging state of water environment had not been improved as necessary and it was still in a deteriorating state. Therefore, we should enhance the water environment improvement measures so as to achieve a benign coupling of coordinated symbiosis in the composite system. This stage is to further protect the water environment and achieve a critical period of harmonious development of social economy and environmental protection.

4. Conclusion

Based on the principal component analysis and the coupling coordination model, this paper establishes a corresponding evaluation index system to quantitatively analyze the coordinated development of social economy and water environment in the Ganjiang River basin. The results show that the coordination between the social and economic growth of the basin and the evolution of water environment quality is not ideal, and the coupling effect between the two is also in a weak state of development. 2006 is a time node, and before 2006, it lags behind in social and economic development and it is in an uncoordinated stage of development, and the social and economic development has not yet reached the maximum of self-regulation of water environment. The contradictions between social–economic development and the deterioration of water environment gradually appear. The mutual coupling states of the two are changed from low-level coupling to antagonistic coupling and then to low-level coupling again. After 2006, the water environment is lagging and the development of society and economy is beyond the maximum of water environment self-regulation capacity. The social economy in this stage has the financial, technological and other capabilities to improve the quality of water environment. Under this action, the degree of coordination between the two reached barely reconciling state, the role of interaction coupling mostly at a low level of coupling. Although the coordination is relatively high, the results show that the state of water environment lagging has not been significantly changed. In this phase, the influential factors that affect the coordination and coupling degree between social–economic development and water quality should be analyzed in depth. Besides, we should increase environmental investment, adjust industrial structure, strengthen industrial waste-water treatment and improve the domestic sewage pipe network. Benign coordinated symbiosis will be attained in Ganjiang River basin, and sustainable economic and environmental development will be achieved.

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