The coupling relation of man-land system based on temporal evolution analysis in Guangxi Xijiang River Basin

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Abstract. The man-land system is a macro system consisted of nature, society and economy, which is of great significance to the regional management and sustainable development. However, the system presents many challenges and disharmonies especially in river basin regions. It is not only the largest area where human disturbances occur but also the most concentrated area of anthropogenic activities. So, the Xijiang River Basin in Guangxi, which is one of the emerging national strategies, was taken as the study area. And the man-land system of the study area can come down to the resources and environment subsystem and social economy subsystem. First, the evaluation index system was established by selecting 25 relatively evaluation indexes. The variable coefficient was applied to calculate the index weight. Then, the coupling model, which was developed based on system theory, was introduced to figure out the coupling degree and coupling coordination degree of the man-land system of the study area. The results indicated that the development of social economy system presented ascending trend accompanied with resources and environment system presented fluctuated ascending trend. From 2005 to 2014, the coupled states of the man-land system developed from low level harmonize to medium level harmonize.

1. Introduction

The man-land system is the essential issue of the geography and ecology, and its regulation is the one of the most important foundation for regional sustainable development. In recent years, many researches turned to focus on the regional man-land system of the river basin [1]. With the high speed development of social economy and the intensified anthropogenic activities, more natural resources and ecological environment were required to invest into regional development. Then, the resource and environment subsystem faced the stress from the social economic subsystem, which brought the vulnerability and susceptibility to the river basin [2].

The discussions of man-land relationship are mainly qualitatively in the early stage, by analysing the impact on the ecological environment from anthropogenic activities and the planning and management of the river basin [3,4]. Recent researches explored the man-land relationship from the perspective of the water resources optimal allocation, and identified the major impact factors of the
system by applying the principal component analysis and grey correlation analysis [5,6]. With the development of quantitative research, the coupling model was introduced to evaluate the regional man-land system [7,8], which provided scientific method for relative studies.

After the national strategy-Development Planning of Zhujiang-Xijiang Economic Zone 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 [9]. The resources, environment and ecosystem of Xijiang river basin has faced stress from the accelerated and intensified development of economy, and resulted in ecological environment deterioration and conflict of man-land system. Therefore, it is of great significance and urgency to explore the man-land relationship of the Xijiang river basin.

The man-land relationship is a compound system that comprises nature, economy and society, so it is necessary to analyse the man-land relationship from different perspectives for different river basins [10]. In consequence, we established the evaluation index system of man-land relationship in allusion to the specific characteristics of Guangxi Xijiang river basin. Then, the dynamic coupling model was applied to quantitatively evaluate the degree of coupling of man-land system, which is expected to provide a feasible reference for sustainable development of the river basin.

2. Materials and methods

2.1. 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 2.02×10^5 km^2 in the Guangxi Zhuang Autonomous Region, which accounted for 85.54% of the land area of Guangxi (figure 1) [11]. As part of the national development strategy, the Xijiang River Basin occupies an important strategic position in China Western Development.

![Figure 1. Location of the study area.](image)

In this study, the eleven 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 and Chongzuo. And the city was taken as the unit to obtain the evaluation index.

2.2. Evaluation index system
The man-land relationship system of Guangxi Xijiang river basin was reduced to resources and environment subsystem and social economy subsystem according to the specific features of the study area. The index was selected based on the following principles: 1) goal-oriented. The index should be selected according to the consideration of the research objectives; 2) comprehensiveness and scientificity. The relevant literatures have been collected from widely used SCI & CNKI database and counted up the frequentness of index, which represented aspects of the man-land system. Then, the index with higher frequencies were selected; 3) operability. The evaluation index should be easy to access and operable, which was conducive to the research [12].

2.3. Index weight

- Data standardization. The original data always have different dimension and order of magnitude. So the extremum standardization method was applied to make the index being dimensionless. As the difference of the positive and negative effect for index system, the different equations were applied for the two kinds of index:

Positive effect index: \( Z_{ij} = \frac{x_{ij} - \min(x_j)}{\max(x_j) - \min(x_j)} \)  

Negative effect index: \( Z_{ij} = \frac{\max(x_j) - x_{ij}}{\max(x_j) - \min(x_j)} \)  

Where, \( i \) is year, \( j \) is the serial number of the index, \( x \) is the data value, \( \max(x_j) \) and \( \min(x_j) \) are the maximum and minimum values of the index \( j \) in year \( i \) respectively. \( Z \) is the result of the standardization and it is in the range of 0 to 1.

- The coefficient of variation method was applied to calculate the weight of the evaluation index system [13].

\[ W_j = V_j / \sum_{j=1}^{m} V_j \]  

Where \( V_j \) is the variable coefficient of index \( j \). The weight of the index would be higher if \( V_j \) is higher. Among which \( V_j = S / P \), \( S \) is the standard deviation of index \( j \), \( P \) is the mean value of index \( j \).

2.4. Coupling model

The coupling is the interaction and effect degree of two or more systems, which expresses the gradual progress and situation of interdependency and stress among systems or factors of one system at a certain time. It has influence on the characteristics and law of the phase change of the system [14]. In this study, the capacity coupling coefficient was introduced to acquire the coupling model of interactional multi-system.

\[ C_n = \frac{(U_1 \cdot U_2 \cdot \cdots \cdot U_n)}{[\prod (U_i + U_j)]^{1/n}} \]  

So the degree of coupling model of man-land system in Guangxi Xijiang river basin was defined as follow based on the above model:

\[ C = \left( \frac{S(x) \cdot E(y)}{[S(x) + E(y)]^{2}} \right)^r \]  

\[ S(x) = \sum_{i} a_i x_i \]  

\[ E(y) = \sum_{j} b_j y_j \]
Where, $S(x)$ is the resource and environment subsystem, $E(y)$ is the social economy subsystem. $C$ is the degree of coupling of man-land system, $U$ is the subsystem of the whole ecosystem, $r$ is the accommodation coefficient and $r = 1/2$, $a$ and $b$ are the weight of the evaluation index calculated from the coefficient of variation method respectively, $x_i$ and $y_j$ are the evaluation index values after standardization.

The degree of coupling value ranges from 0 to 1. When $C$ approaches to 0, the degree of coupling is the minimum. The resource and environment subsystem is unrelated to the social economy subsystem and the whole system develops toward a disordered state. On the other side, when $C$ approaches to 1, the degree of coupling reaches the highest level. The whole system develops toward a new orderly state. According to the previous research, the degree of coupling of man-land system of the study area was divided into four stages [15]. When $0 < C \leq 0.3$, the resource and environment subsystem and the social economy subsystem was in low level coupling stage. The development intensity of the resource and environment was very low and could keep in affordable range. When $0.3 < C \leq 0.5$, the resource and environment subsystem and the social economy subsystem was in antagonism stage. With the high-speed development of social economy, the resource and environment were destroyed and deteriorated. The resource and environment subsystem could not afford the effect of the development of the social economy subsystem. When $0.5 < C \leq 0.8$, the resource and environment subsystem and the social economy subsystem was in benign coupling stage. When $0.8 < C \leq 1$, the resource and environment subsystem and the social economy subsystem were in high level coupling stage. The two systems promoted mutually and stayed in an optimal development stage.

2.5. Coupling coordination degree model

Coupling degree is the index that reflected the dynamic correlation of the subsystem in the man-land system, which played an important role in determining the intensity of the mutual effect of the two subsystems [16]. However, it is not able to reflect the cooperatives of the resource and environment subsystem and the social economy subsystem comprehensively which may cause certain deviations. As a consequence, the coupling coordination degree model of the man-land system was established to reflect the relevance of two subsystems better.

$$D = (C \cdot R)^{1/2} \quad (8)$$

$$R = a \cdot S(x) + b \cdot E(y) \quad (9)$$

Where, $D$ is the coupling coordination degree, $C$ is the coupling degree of man-land system, $R$ is the comprehensive coordination index of man-land system, which reflected the synergistic effect or contribution value of the resource and environment subsystem and the social economy subsystem. $a$ and $b$ are the undetermined coefficients. The coupling coordination degree and variation trend of the two subsystems could be diagnosed based on $D$.

The coupling coordination degree was categorized into four types in the light of the available researches and literatures [17]. When $0 < D \leq 0.4$, the system is in the state of low coordination stage. When $0.4 < D \leq 0.5$, the system is in the state of medium coordination stage. When $0.5 < D \leq 0.8$, the system is in the state of high coordination stage. When $0.8 < D \leq 1$, the system is in the state of extreme coordination stage (table 1).

| Coupling degree | Coupling coordination degree | State description                  |
|-----------------|-------------------------------|------------------------------------|
| $0 < C \leq 0.3$| $0 < D \leq 0.4$             | Low coordinating low level coupling|
| $0.4 < D \leq 0.5$ | High coordinating low level coupling|
| $0.5 < D \leq 0.8$ | Low coordinating antagonism stage |
| $0.3 < C \leq 0.5$ | $0 < D \leq 0.4$             | Medium coordinating antagonism stage |
| $0.4 < D \leq 0.5$ | High coordinating antagonism stage |
| $0.5 < D \leq 0.8$ | Low coordinating antagonism stage |
3. Results and discussion

3.1. Evaluation index system and weight

With the consideration of internal relation of the two subsystems in the man-land system, ten factors were chosen to represent the resource and environment subsystem and eleven factors were chosen to represent the social economy subsystem (table 2). The population and economic data were obtained from the statistical yearbooks (2006-2015). The water resource data were selected from Guangxi water resources bulletin and the statistical database of environmental protection and social economic development and so on.

Table 2. Evaluation index system and weight of coupled human-natural system in Guangxi Xijiang River Basin.

| Objective level | Subsystem | Criterion level | Index level | Weight |
|-----------------|-----------|-----------------|-------------|--------|
| Coupling of man-land system $C$ | Social economy $S$ | Population structure | $S_{11}$ Total population | 0.0501 |
|                 | Economic level | | $S_{12}$ Proportion of agricultural population | 0.0625 |
|                 | | | $S_{13}$ Per capita GDP | 0.0549 |
|                 | | | $S_{14}$ Per capita gross industrial output | 0.0587 |
|                 | | | $S_{15}$ Total social fixed assets investment | 0.0585 |
|                 | | | $S_{16}$ Total Social Retail Sales | 0.0589 |
|                 | | | $S_{17}$ Local financial revenue | 0.0472 |
|                 | Social development | | $S_{21}$ Rural Engle index | 0.0551 |
|                 | | | $S_{22}$ Urban Engle index | 0.0336 |
|                 | | | $S_{23}$ Per capita urban road area | 0.0389 |
|                 | | | $S_{24}$ Per capita daily water consumption | 0.0619 |
| Environment and Resource $E$ | Resource conditions | | $E_{11}$ Mean annual precipitation | 0.0389 |
|                 | | | $E_{12}$ Forest coverage | 0.0577 |
|                 | | | $E_{13}$ Annul runoff | 0.0434 |
|                 | | | $E_{14}$ Gross water resource per capita | 0.0479 |
|                 | Stress and management of ecological environment | | $E_{21}$ Per capita arable land | 0.0480 |
|                 | | | $E_{22}$ Per capita grain production | 0.0381 |
|                 | | | $E_{23}$ Green coverage rate of built-up area | 0.0327 |
|                 | | | $E_{24}$ Per capita sewage discharge | 0.0263 |
|                 | | | $E_{25}$ Per capita industrial wastewater discharge | 0.0505 |
|                 | | | $E_{26}$ Per capita sewage treatment capacity | 0.0366 |

3.2. Comprehensive analyse of coupling process of man-land system

The social economy subsystem. Comprehensive development of the social economy subsystem presented stabilized ascending trend from 2005 to 2014. The comprehensive index has risen from 0.1064 of 2005 to 0.4481 of 2014, which was about 4.2 times overall (figure 2). The per capita GDP has increased 3.9 times compared with 2005. The per capita gross industrial output increased nearly 6.6 times. The total social fixed assets investment and local financial revenue increased 7.2 times and 2.5 times respectively. At the same time, the living standard of the people has been greatly improved. The proportion of agricultural population was around 0.8 and remained stable during the ten years. Both the rural Engle index and urban Engle index presented decreased trend. In addition, the per capita urban road area increased 1.3 times and the total social retail sales increased 4 times. All the above
indicated that the strength of the social economy has been enhanced remarkably.

![Figure 2. Coupling degree of man-land system in Guangxi Xijiang River Basin.](image)

The resource and environment subsystem. The development of the resource and environment subsystem presented ascending trend with fluctuation accompanied by the development of social economy during the ten years. The comprehensive index increased from 0.1618 of 2005 to 0.3616 of 2014, which was about 2.2 times overall (figure 1). The green coverage rate of built-up area increased 13% and the forest coverage increased 5%. The increment of gross water resource per capita and arable land were 1.18 times and 1.5 times respectively. The per capita sewage discharge and the per capita industrial wastewater discharge didn’t change evidently, while the per capita sewage treatment capacity increased gradually to 1.75 times.

As a whole, the development of the social economy presented stabilized ascending trend with the obvious response of the resource and environment. With the development of social economy subsystem, the resource and environment subsystem has shown the fluctuated state of improvement-deterioration. The comprehensive index value of the social economy subsystem was 0.1064 in 2015, which was lower than the comprehensive index value of the resource and environment subsystem. This is due to the low economic aggregate and low level industrialization and urbanization in that stage. In the year of 2007, the comprehensive index value of the resource and environment reached the minimum, while the per capita GDP and gross industrial output increased significantly. The per capita sewage treatment capacity also increased accordingly. These indicated that the development of the social economy was at the cost of the resource and environment. After the economic crisis in 2008, the development of economy recovered and accelerated, which caused the stress on regional resources and environment. At the same time, the environment issues had been paid more and more attention. With the strengthened improvement of the environment, the contradiction of the two subsystems was alleviated and the comprehensive index value of the resource and environment subsystem has been raised again.

3.3. Coupling state analyse of the man-land system

The coupling degree and coupling coordination degree of the study area from 2005 to 2014 were calculated (table 3).

| Year | Social Economy Subsystem | Resource and Environment Subsystem |
|------|--------------------------|-----------------------------------|
| 2005 | 0.25                     | 0.45                               |
| 2007 | 0.30                     | 0.40                               |
| 2009 | 0.35                     | 0.45                               |
| 2011 | 0.40                     | 0.50                               |
| 2013 | 0.45                     | 0.55                               |

Table 3. Coupling states of man-land system in Guangxi Xijiang River Basin.
| Year | Coupling degree $(C)$ | Coupling coordination degree $(D)$ | Types                        |
|------|----------------------|-----------------------------------|------------------------------|
| 2005 | 0.4892               | 0.2561                            | Low coordinating antagonism stage |
| 2006 | 0.4999               | 0.3281                            | Low coordinating antagonism stage |
| 2007 | 0.4897               | 0.2527                            | Low coordinating antagonism stage |
| 2008 | 0.4963               | 0.3088                            | Low coordinating antagonism stage |
| 2009 | 0.4960               | 0.3306                            | Low coordinating antagonism stage |
| 2010 | 0.5000               | 0.3621                            | Low coordinating antagonism stage |
| 2011 | 0.4949               | 0.3649                            | Low coordinating antagonism stage |
| 2012 | 0.4992               | 0.4242                            | Medium coordinating antagonism stage |
| 2013 | 0.4999               | 0.4347                            | Medium coordinating antagonism stage |
| 2014 | 0.4971               | 0.4486                            | Medium coordinating antagonism stage |

The coupling degree between the two subsystems from 2005 to 2014 was in the range of 0.48 to 0.5 with no obvious fluctuations. The coupling was in the antagonism stage, which indicated that the synergistic effect of the social economy subsystem and the resource and environment subsystem was not strong and the interaction of the two systems was low. Combined with the coupling coordination degree, the coupling states of man-land system of the Guangxi Xijiang River Basin from 2005 to 2014 were divided into two stages, i.e. low coordinating antagonism stage from 2005 to 2011 and Medium coordinating antagonism stage from 2012 to 2014.

During the low coordinating antagonism stage from 2005 to 2011, the coupling degree presented cyclical fluctuation trend of up-down. The coupling degree reached the maximum value of 0.5 in 2010, which indicated that the coupling states of man-land system has the tendency of transition to the adjusted stage. The coupling coordination degree was less than 0.4 and in low coordinating state with fluctuation. During this period, the national strategy of ‘Two Zone Areas’ was the key factor that accelerated the development of the social economy of the study area. Meanwhile, the implementation of energy conservation and emission reduction of the national policies played an important role in protecting the environment. The energy consumption and pollution discharge of the involved industries decreased significantly.

During the medium coordinating antagonism stage from 2012 to 2014, the coupling was in the antagonism stage and has the tendency of transition to the adjusted stage. The coupling coordination degree was in the medium coordinating state and increased obviously compared with the previous stage, which showed that the confliction of the two subsystems was alleviated. The Twelfth Five-Year Plan of the study area has been proposed the target of multi-billion industries, which included the petrochemical industry, metallurgy, paper and wood processing industry. The development of these industries have negative effects on the environment of the river basin. However, the concepts of green and continuous development were also promoted, which could boost the ecological civilization construction of the river basin.

4. Conclusions

The man-land system is of great significance to the regional management and sustainable development. According to the characteristic of the Guangxi Xijiang River Basin, the man-land system of the study area was resolve into the resources and environment subsystem and social economy subsystem. And 25 evaluation indexes were selected to represent the subsystems. Based on the system theory, the dynamic coupling model was applied to quantitatively evaluate the coupling degree and coupling coordination degree of the man-land system.

The strength of the social economy has been enhanced remarkably, while the resource and environment subsystem shown the fluctuated state. The coupling states of man-land system of the Guangxi Xijiang River Basin was low coordinating antagonism stage from 2005 to 2011 and medium coordinating antagonism stage from 2012 to 2014. The results revealed the current situation of the study area from the perspective of natural and social systems, which was expected to provide some evidences for the management of the river basin.
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References
[1] Gao C, Lei J and Jin F J 2013 The classification and assessment of vulnerability of man-land system of oasis city in arid area Front Earth Sci 7 406-16
[2] Yu G M, Zeng Q, Yang S, Hu L M, Lin X W, Che Y and Zheng Y G 2010 On the intensity and type transition of land use at the basin scale using RS/GIS: A case study of the Hanjiang River Basin Environ Monit Assess 160 169-79
[3] Torkil J C and Jens F 2001 Firming up the conceptual basis of integrated water resources management Int J Water Resour D 17 501-10
[4] Qu G P 2002 The problems of the ecological environmental have become a popular subject of country safety Environ Conserv 5 3-5
[5] Wandersee S M, An L, David L C and Yang Y Q 2012 Perception and decisions in modeling coupled human and natural systems: a case study from Fanjingshan National Nature Reserve, China Ecol Model 229 37-49
[6] He X, Lin Z S and Xiong K N 2015 Using a coupled human-natural system to assess the vulnerability of the karst landform region in China Sustainability 7 12910-25
[7] Kumar U and Ridder K 2010 GARCH modeling in association with FFT-ARIMA to forecast ozone episodes Atmos Environ 44 4252-65
[8] Li Q and Ren Z Y 2012 Energy production and consumption prediction and their response to environment based on coupling model in China J Geogr Sci 22 93-109
[9] Wu Z Y, Lin Q X, Lu G H, He H and Qu J 2015 Analysis of hydrological drought frequency for the Xijiang River Basin in South China using observed streamflow data Nat Hazards 77 1655-77
[10] Kok J L, Kofalk S, Berlekamp J, Hahn B and Wind H 2009 From design to application of a decision-support system for integrated river-basin management Water Resour Manag 23 1781-811
[11] Yan Y, Shi S N, Hu B Q and Yang K S 2018 Ecological risk assessment of Guangxi Xijiang river basin based on landscape pattern Ekoloji 27 5-16
[12] Orfanidis S, Panayotidis P and Stamatis N 2003 An insight to the ecological evaluation index (EEI) Ecol Indic 3 27-33
[13] Castillo J and Padilla M 2015 Modeling extreme values by the residual coefficient of variation Sort-Stat Oper Res T 40 303-20
[14] Noel P H and Cai X M 2017 On the role of individuals in models of coupled human and natural systems: Lessons from a case study in the Republican River Basin Environ Model Softw 92 1-16
[15] Lu H L, Zhou L H, Chen Y, An Y W and Hou C X 2017 Degree of coupling and coordination of eco-economic system and the influencing factors: A case study in Yanchi County, Ningxia Hui Autonomous Region, China J Arid Land 9 446-57
[16] Sun N and Hall M 2016 Coupling human preferences with biophysical processes: modeling the effect of citizen attitudes on potential urban stormwater runoff Urban Ecosyst 19 1433-54
[17] Xing L, Xue M G and Hu M S 2019 Dynamic simulation and assessment of the coupling coordination degree of the economy−resource−environment system: Case of Wuhan City in China J Environ Manage 230 474-87