Research of Coupled Coordination Degree of Water Resources, Energy and Food System in Henan Province From 2008 to 2018

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Abstract: With decrease of water resources and increase of energy demand in social life, uncertainty of food supply, which becomes severe, increase necessity of initiating a study of the degree of the coupled coordination among these three subsystems. Taking Henan Province as the research object, this paper calculates the coupled coordination degree in Henan Province from 2008 to 2018 by referring the coupling model. The results show that the degree of the coupled coordination of these three is divided by 2013, showing high coupling and extreme coupling state.

Key words: Water Resources; Energy; Food; Coupling Coordination; Henan Province.

1. Introduction

Water resources, energy and food are essential resources for human survival. Most current researches on water resources, energy and food focus on the relationship between single or two areas, while ignoring the links among three of them. However, energy development requires water, water purification and dispatching also need energy, meanwhile food production and irrigation are inseparable from water and energy; these three are interdependent and closely linked.

Henan Province is the largest food production province in China, the cultivated land area is 12168.34 million mu, and the cultivated land per capita is 1.27 mu [1]. Besides, Henan is a major output province of mineral resources and its mining output value ranks among the top five in the country for many years. However, recently, Henan's energy consumption has grown rapidly. In 2013, the energy consumption intensity of Henan Province reached 41.76%, which is 50% higher than the developed areas such as Beijing and Guangdong [2]. As for water resources, Henan Province spans the Yangtze River, Huai River, Yellow River and Hai River basins, the average annual water resources are 40.353 billion cubic meters, and the per capita water resources are about 376 cubic meters, which is less than 1/5 of the national average [3]. Coordinating the relationship among water resources, energy, and food is an important topic and it would be of great practical significance for investigating the sustainable development. On the basis of traditional coupling, this paper considers the comprehensive evaluation of Water resources, energy and food system in Henan Province in 2008-2018 and introduces a coupled coordination degree model to quantify the state of coupling in the province, providing reference for the sustainable development of water resources, energy and food in Henan Province.
2. Research methods and Data sources

2.1. The coupled coordination degree model

According to the scientific connotation of Water resources, energy and food system, 8 critical indicators from each subsystem were selected to establish a comprehensive evaluation index system; as for each indicator, $X_{ij}$ means the value for the i year and the jth indicator, where $i=1,2,\ldots,11; \ j=1,2,\ldots,8$.

$f_1(x), f_2(x)$ are the comprehensive evaluation value of each indicator in 3 subsystems, indicate the proportion and importance of the indicator in the whole system, the formula is as follows.

$$f_n(x)=\sum_{j=1}^{8} X_{ij}W_{ij}$$

Using the coefficient of variation method to determine the weight of each indicator $W_{ij}$

$$W_{ij}=\frac{V_{ij}}{\sum_{j=1}^{8} V_{ij}}$$

$$V_{ij}=\frac{\sigma_{ij}}{\bar{x}_{ij}}$$

Where $\sigma_{ij}, \bar{x}_{ij}, V_{ij}$ are value and coefficient of variation for the jth item in year i.

The coupling represents the direct and weak relation of each subsystem. According to the actual situation of Henan Province and the research of Shihong Yang [4], the formulas of coupling model are as follows:

$$C=\left\{\frac{f_1(x)f_2(x)\ldots f_n(x)}{f_1(x)+f_2(x)+\ldots+f_n(x)}\right\}^n$$

Since there are 3 subsystems, the coupling formulas would be:

$$C=\left\{\frac{f_1(x)f_2(x)f_3(x)}{f_1(x)+f_2(x)+f_3(x)}\right\}^3$$

In order to further reflect the development level, the coupled coordination degree model is introduced:

$$D=\sqrt{CT}$$

$$T=\alpha_1 f_1(x)+\alpha_2 f_2(x)\ldots+\alpha_n f_n(x)$$

Where $D$ is the coupled coordination degree, $T$ is the comprehensive evaluation index of the whole system, $\alpha_1, \alpha_2, \alpha_n$ are undetermined coefficients.

As mentioned, $n=3$, to ensure the coordinated development of water resources, energy and food, so $\alpha_1 = \alpha_2 = \alpha_3 = \frac{1}{3}$. 

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\[ T = \frac{1}{3} f_1(x) + \frac{1}{3} f_2(x) + \frac{1}{3} f_3(x) \]  

(8)

2.2. Data source

The data used in this paper comes from the National Bureau of Statistics, Henan Water Resources Bulletin, Henan Statistical Yearbook, China Energy Statistical Yearbook, China Grain Yearbook and so on, in which some missing data is estimated by linear fitting method. Based on the existing research results, this paper uses Caizhi Sun and Xiaodong Yan's research method [5] under the 3 subsystems, 8 important indicators are selected according to the actual situation. In addition, in order to maintain the consistency of units, all data have been dimensionless. The weight of each indicator has been calculated according to formula (2)(3). Then the name, weight and nature of comprehensive evaluation index of water resources, energy and food in Henan from 2008 and 2018 are shown in table 1.

Table 1. Comprehensive evaluation index of water resources, energy and food in Henan Province from 2008 to 2018

| Subsystem       | Index                                           | Weight | Value  | Nature of Index |
|-----------------|-------------------------------------------------|--------|--------|-----------------|
| Water resources | Industrial production value of 10,000 yuan       | 0.125  | -      |                 |
|                 | Total water consumption per unit of GDP         | 0.152  | -      |                 |
|                 | The percentage of domestic water consumption    | 0.186  | +      |                 |
|                 | The percentage of agricultural water consumption| 0.089  | -      |                 |
|                 | The percentage of industrial water consumption  | 0.119  | -      |                 |
|                 | The percentage of ecological water consumption  | 0.148  | +      |                 |
|                 | Inflow of water                                 | 0.094  | +      |                 |
|                 | Outbound water volume                           | 0.087  | -      |                 |
| Energy          | Per capita energy production                    | 0.146  | +      |                 |
|                 | Per capita energy consumption                   | 0.184  | -      |                 |
|                 | Energy imports                                  | 0.171  | +      |                 |
|                 | Energy export volume                            | 0.099  | -      |                 |
|                 | The proportion of primary industry              | 0.067  | -      |                 |
|                 | The proportion of secondary industry            | 0.162  | -      |                 |
|                 | The proportion of tertiary industry             | 0.102  | +      |                 |
|                 | Energy consumption price index                  | 0.089  | -      |                 |
| Food            | Proportion of food sown area                    | 0.126  | +      |                 |
|                 | Food yield per unit area                        | 0.028  | +      |                 |
|                 | Food production volatility                      | 0.130  | -      |                 |
|                 | Town Engel coefficient                          | 0.194  | -      |                 |
|                 | Rural Engel coefficient                         | 0.180  | -      |                 |
|                 | Per capita food consumption                     | 0.135  | -      |                 |
|                 | Per capita food possession                      | 0.076  | +      |                 |
|                 | Food consumer price index                       | 0.061  | -      |                 |

3. Results and analysis

Using the comprehensive evaluation index obtained in Table 1 for each subsystem, the coupled coordination degree D is calculated using the formula (5)(6)(8) and shown in table 3. According to the division by Zhongbin Liao in 1999[6], D values are grouped and divided into 4 states as table 2. When the D is in the interval of 0<D≤0.4, the system is in the low coupled state, which means there is basically no or only a little coupling relationship between these subsystems; ; when 0.4<D≤0.6, the system is in the moderate coupled state and although there is coupling relationship between each other, the degree of coupling is medium; when 0.6<D≤0.8, the system is in the highly coupling state, in this level, the coupling relationship between subsystems is very close, but there is still a lot of room to improve;when
D>0.8 The system is in an extremely coupling state, which means the coupling relationship in subsystems is extremely close, interdependent and inseparable.

Table 2. The coupled state of D in different value.

| D     | 0<D≤0.4 | 0.4<D≤0.6 | 0.6<D≤0.8 | D>0.8 |
|-------|---------|-----------|-----------|-------|
| State | low     | moderate  | high      | extreme |

Table 3. The degree of coupling coordination of Water resources, energy and food system in Henan Province from 2008 to 2018.

| Year | Water Resources f(x) | Energy f(x) | Food f(x) | C     | T     | D     | Coupling state |
|------|-----------------------|-------------|-----------|-------|-------|-------|----------------|
| 2008 | 0.469                 | 0.494       | 0.527     | 0.558 | 1.004 | 0.749 | high           |
| 2009 | 0.506                 | 0.485       | 0.655     | 0.549 | 0.985 | 0.735 | high           |
| 2010 | 0.530                 | 0.528       | 0.655     | 0.570 | 0.991 | 0.752 | high           |
| 2011 | 0.504                 | 0.546       | 0.386     | 0.575 | 0.980 | 0.751 | high           |
| 2012 | 0.519                 | 0.542       | 0.742     | 0.605 | 0.977 | 0.768 | high           |
| 2013 | 0.441                 | 0.535       | 0.821     | 0.610 | 0.944 | 0.759 | high           |
| 2014 | 0.463                 | 0.537       | 0.845     | 0.626 | 0.945 | 0.769 | high           |
| 2015 | 0.526                 | 0.515       | 0.673     | 0.653 | 0.953 | 0.789 | high           |
| 2016 | 0.497                 | 0.541       | 0.840     | 0.757 | 0.877 | 0.815 | extreme        |
| 2017 | 0.495                 | 0.545       | 0.879     | 0.771 | 0.869 | 0.819 | extreme        |
| 2018 | 0.492                 | 0.548       | 0.918     | 0.786 | 0.860 | 0.822 | extreme        |

According to the division of coupling states, before 2015, water resources, energy and food system in Henan Province were highly coupled. From 2016, all were extremely coupled. Figure 2 shows the change of D in the past 11 years. Before 2014, the coupled coordination degree of Henan Province has fluctuated, which means although Henan Province is a resource province and has a large output, the imbalance between supply and demand is still serious. However, since 2015, the coupled coordination degree has gradually increased with time, indicating that in the face of water shortage, energy exhaustion, and small cultivated land area, the government endeavors to solve this problem, specifically, improving the efficiency of using resource efficiency, finding alternative energy sources, and increasing grain yields. Based on the development trend of graphics, it can be predicted that the degree of coupled coordination of the three subsystems in Henan Province will continue to rise in the future, it also reflects the success of sustainable development in Henan Province and the correct policy guidance in Henan Province from the side.
Figure 1. Coupled coordination degree of Water resources, energy and food system in Henan Province from 2008 to 2018.

4. Conclusion
In this paper, the water resources, energy and food system coupling coordination model is constructed, and the comprehensive evaluation index and coupled coordination degree in Henan Province are analyzed and explored. The analysis results are consistent with the actual situation. In the coupled coordination degree model, the degree is calculated, and the coupling state is distinguished and categorized. it is highly coupled between 2008 and 2013, and extremely coupled in 2014-2018. The coupled coordination degree of water resources, energy and food in Henan Province is a reflection of the comprehensive effects of Henan's policy on economic development and ecological environment. The degree of coupling is possible to keep growing in the future, which means the water resources, energy and food would promote sustainable development throughout Henan Province.

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