Evaluation Method of Water Resource Contribution Rate in Terms of Emergy

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Abstract. As an important resource, water resource has an important contribution to the development of the social economy system. Now the majority of study concentrated on the qualitative analysis and the quantitative analysis is not enough. Based on emergy theory, according to the flow and transformation of water resources in the social economic system, water resources emergy contribution rate (*WECR*) is put forward in this paper, to reflect the contribution of water resources. And the quantization method of *WECR* to agriculture, industry, and social life is presented in terms of emergy, which provide a new method for the research of water resources contribution for economic and social development. Taking Zhengzhou as an example, the *WECR* to agriculture, industry, and social life was calculated from 2005 to 2015, and the average annual contribution rate was 8.55%, 3.68%, 4.71%, respectively. The results showed that water resources have the greatest contribution to agriculture and the lowest contribution to industry. In terms of the trend, from 2005 to 2015, the contribution rate of water resources to agriculture and industry in Zhengzhou city has increased significantly, and the contribution rate to social life has remained within a certain range of values, with slight fluctuations in different years.

1. Introduction

Water resource, as one of the irreplaceable natural resources in economic production and social life, has undoubtedly contributed to the social economy. How to scientifically analyze and measure the contribution of water resources to the social and economic forms is a hot issue in academic research [1]. In view of this problem, domestic and foreign scholars carry out a lot of research [2]. In terms of conceptual research on the contribution of water resources to socio-economic systems, different scholars have different opinions. Some scholars believe that the marginal benefit of water resources is the contribution of water resources to economic production. Some scholars believe that the elasticity coefficient of water resources is the contribution rate of water resources to the social economy [3]. In terms of quantitative evaluation methods, according to the literature review, the current research methods are mainly economic methods, such as the Cobb-Douglas production function method [4], CES production function method [5] and slow production function method [6]. These methods are based on the monetary theory of economics [7], trying to value water resources and human activities, and measuring everything in terms of money. But in fact, money is only a tool to measure the role and contribution of economic activity, and the circulation of money does not pass

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through the natural ecosystem [8], and it is not easy to accurately measure the contribution of water resources.

Based on the theory of emergy, the concept of water resources emergy contribution rate (*WECR*) and its quantification method are put forward, which can provide new ideas for the research of water resources contribution to regional economic production and contribute to the diversified development of water resources contribution rate calculation method. Taking Zhengzhou city as an example, the *WECR* to agricultural, industry and social life from 2005 to 2015 was calculated and the variation regularity of contribution rate was analyzed.

2. Water resources emergy contribution rate and its quantification method

2.1. Emergy theory and analytical methods

The theory and methods of environmental emergy accounting were developed by the well-known American ecologist and systems emergy analysis pioneer H. T. Odum. This approach provided a new way to analyze ecological economic systems and is widely used in quantitative research into the relationship between humans and nature, environmental resources, and social economics [9]. The emergy calculation, simply, put the energy and material into emergy through the solar transformity. The formula used is as follows:

$$M = \tau \times B \tag{1}$$

Where M represents the emergy value (sej), τ represents the solar transformity (sej/J or sej/g), and B represents the quantity of energy or substance (J or g).

2.2. Water resources emergy contribution rate

The contribution of water resources to the society and economy can be described as: In a certain system, the beneficial effect of water resources on society and economy. It is realized through the continuous transfer and transformation of the energy of water resources in the social and economic system, and it is finally embodied in various high-energy products or services. Therefore, we define the Water Resources Emergy Contribution Rate (*WECR*) as the ratio of the net contribution emergy of water resources to the net output emergy of the system. *WECR* is a relative index to measure the contribution of water resources to social and economic. In a certain area, within a certain period of time, the total emergy of the system is certain. The greater the emergy of the water resources is, the greater the *WECR* can be.

2.3. The quantization method of WECR

Studying the contribution of water resources to society and economy needs to find a common measure that can measure the relationship between water resources and human social and economic systems. For a long time, the economic system used the currency to measure the level of economic development and the role and contribution of human beings. However, the currency circulation did not pass through the natural ecosystem and could not measure the contribution and role of water resources and other natural resources. Emergy theory and method, based on solar emergy, provide a common measurement standard for measuring the relationship between nature and economy, and provide quantitative criteria for studying the contribution of water resources to social and economic development [10].

First the energy network diagram is constructed to clarify the input and output of energy in the system. The energy flow, material flow and currency flow of the system are converted into emergy flow through the solar transformity, and *WECR* can be quantified by the ratio of the net contribution emergy of water resources to the net output emergy of the system. In the process of calculation, according to the water user classification standard of China's water resources comprehensive planning, *WECR* can be calculated separately from three sectors of agriculture, industry and life. The specific steps are as follows:

(1) Energy network diagram.

The process of production and life is accompanied by constant energy conversion. So, the water system can be regarded as an energy system. With the circulation, flow and storage of water in the system, the energy network is formed. By constructing the energy network diagram of water system, the structure of the system can be clearly defined, and the transmission and transformation process of the energy in and out of the system is understood.

(2) Calculation of the total emergy of the system (M_U)

The production and living process is abstracted into the input-output process of water resources and other material, information, labor, etc. And the emergy analysis table is compiled, as shown in Table 1. According to Equation 1, the input and output of the system can be calculated. The total input emergy of the system is M_U, the feedback input emergy of the system is M_F, the total output emergy of the system is M_Y, the water input emergy of the system is M_W, and the feedback input emergy of water is M_{WF}.

The total input emergy of the system can be calculated by the following formula.

$$M_U = M_R + M_N + M_{R1} + M_S \tag{2}$$

Where M_R is the emergy input of renewable environmental resource (sej), M_N is the emergy input of nonrenewable environmental resources (sej), M_{R1} is the emergy input of renewable organic energy of human economic and social feedback (sej), M_S is the emergy input of nonrenewable industrial auxiliary energy (sej).

The water input emergy of the system (M_W) can be calculated by multiplying the utilization of water resources in the process of production and living by the water solar transformity. Several types of water resources should be considered in agricultural water use, such as effective precipitation, surface water and groundwater. Industrial water is mainly surface water and groundwater, but it is necessary to pay attention to the problem of reuse of industrial water. Domestic water mainly considers tap water, mineral water and pure water.

(3) Calculation of *WECR*

The *WECR* is the proportion of net contribution emergy of water resources to the net output emergy of the system (NM_Y). The net contribution emergy of water resources (NM_W) is equal to the contribution of water resources to the system minus the feedback emergy input of the system to the water resources. The formula is as follows.

$$NM_W = \frac{M_W}{M_U} \times M_Y - M_{WF} \tag{3}$$

The system net output emergy (NM_Y) is equal to the total output emergy (M_Y) minus the feedback input emergy (M_F). The formula is as follows.

$$NM_Y = M_Y - M_F \tag{4}$$

Therefore, the quantitative formula for *WECR* is as follows:

$$WECR = \frac{NM_W}{NM_Y} = \frac{\frac{M_W}{M_U} \times M_Y - M_{WF}}{M_Y - M_F} \times 100\% \tag{5}$$

3. Water resources emergy contribution rate in Zhengzhou

According to the method of *WECR*, collect the data of socio-economic, natural environment and water resources in Zhengzhou and understand the basic structure of socio-economic system in Zhengzhou. The relevant data of water resources were obtained from Zhengzhou water resources bulletin (2005~2015).

The social and economic data were obtained from Zhengzhou Statistical Yearbook (2006~2016) and Henan Statistical Yearbook (2006~2016). The data of solar transformity of different water bodies and the ratio of emergy to money in Zhengzhou were derived from the previous research results [10]. The solar transformity of other materials and energy refer to the research results of S F Lan et al [9].

3.1. The WECR to agriculture of Zhengzhou

According to the relationship between the main energy flow, material flow and currency flow in the agricultural sector of Zhengzhou, the energy system network diagram of agriculture is constructed, as shown in Figure 1 (see ref. [9] for illustration).Taking the year of 2005 as an example, the calculation of *WECR* to agriculture in Zhengzhou city is shown in Table 1. The summary results of *WECR* to agriculture from 2005 to 2015 are shown in Table 2.

Table 1. The emergy analysis table of *WECR* to agriculture of Zhengzhou in 2005.

Item of agriculture	Data	unit	solar transformity (sej/unit)	Emergy (10^{20}sej)
1 Input				
1.1 Renewable resources				
1.1.1 sunlight	3.70×10^{19}	J	1.00	0.37
1.1.2 wind	6.29×10^{16}	J	6.23×10^{2}	0.39
1.1.3 water resources	6.82×10^{8}	m^3	1.80×10^{12}	12.26
1.2 Nonrenewable resources				
Topsoil loss	5.60×10^{15}	J	6.25×10^{4}	3.50
1.3 Nonrenewable industrial energy				
1.3.1 electricity	1.20×10^{16}	J	1.59×10^{5}	19.04
1.3.2 diesel	2.01×10^{15}	J	6.60×10^{4}	1.33
1.3.3 fertilizer	21.54×10^{4}	t	6.45×10^{15}	13.9
1.3.4 others	1.26×10^{14}	J	6.82×10^{7}	85.88
1.4 Renewable organic energy				
1.4.1 labour	2.58×10^{15}	J	3.80×10^{5}	9.81
1.4.2 draught power	5.11×10^{14}	J	1.46×10^{5}	0.75
1.4.3 organic fertilizer	1.60×10^{16}	J	2.70×10^{4}	4.27
1.4.4 seeds	4.55×10^{14}	J	2.00×10^{5}	0.91
1.5feedback input				
1.5.1M_F	2.38×10^{9}	￥	7.44×10^{11}	17.71
1.5.2M_{WF}	1.06×10^{8}	￥	7.44×10^{11}	0.79
2 Output				
2.1 Agriculture products				
2.1.1 grain	2.40×10^{14}	J	9.38×10^{6}	22.48
2.1.2 vegetables	4.44×10^{16}	J	2.70×10^{4}	11.98
2.1.3 fruit	7.03×10^{15}	J	5.30×10^{4}	3.72
2.1.4 others	6.06×10^{15}	J	6.92×10^{5}	41.94
2.2 Livestock products				
2.2.1 meat	8.68×10^{15}	J	1.94×10^{6}	168.20
2.2.2 eggs	4.04×10^{15}	J	2.00×10^{6}	80.80
2.2.3 others	6.10×10^{15}	J	2.00×10^{6}	121.97

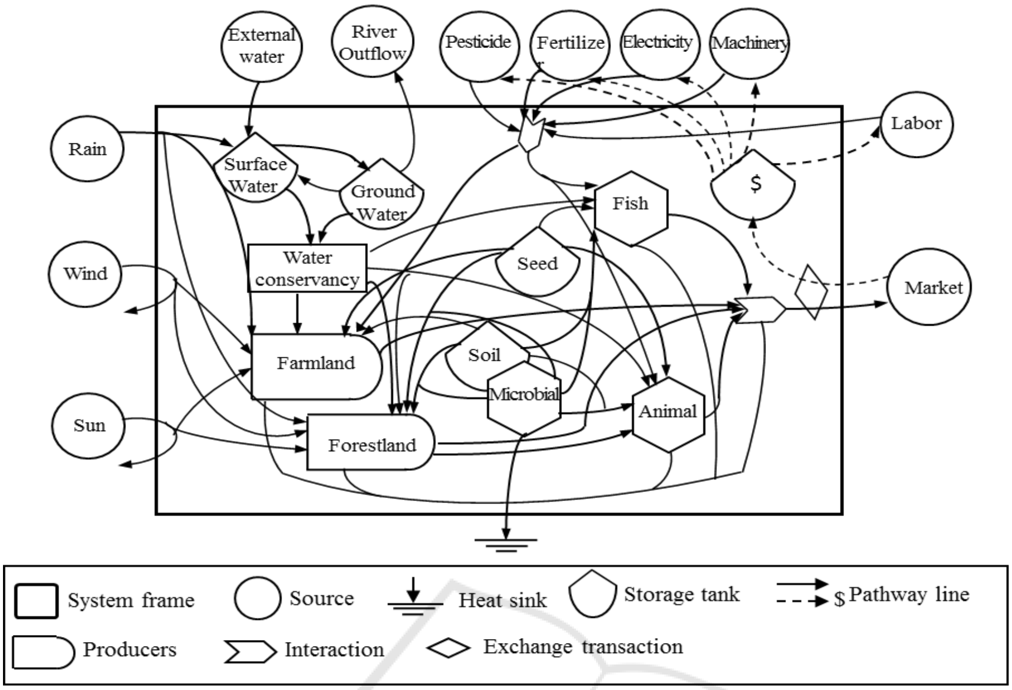

Figure 1. The energy network diagram of agricultural system of Zhengzhou.

Table 2. The summary results of *WECR* to agriculture from 2005 to 2015. (10^{20}sej)

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
M_{UA}	152.40	158.26	161.75	169.32	175.45	180.72	183.94	190.29	197.22	206.73	215.03
M_{WA}	12.25	12.58	13.47	14.19	14.11	14.49	14.92	16.18	16.84	17.30	18.07
M_{YA}	451.09	417.77	448.26	473.21	495.15	512.37	539.06	501.65	537.89	575.52	521.37
M_{FA}	17.71	20.34	21.57	25.03	29.48	30.21	33.27	35.02	38.49	39.05	42.14
M_{WFA}	0.79	0.82	0.75	0.87	0.91	0.97	1.01	1.17	1.23	1.35	1.42
$WECR_A$(%)	8.18	8.15	8.57	8.65	8.36	8.32	8.45	8.89	8.95	8.73	8.85

3.2. The WECR to industry of Zhengzhou

The calculation process of *WECR* to industry in Zhengzhou city is similar to that of the agricultural calculation table. The summary results of *WECR* to industry from 2005 to 2015 are shown in Table 3.

Table 3. The summary results of *WECR* to industry of Zhengzhou from 2005 to 2015. (10^{20}sej)

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
M_{UI}	596.97	635.48	711.71	812.38	919.54	1065.89	1143.55	1225.19	1316.58	1409.76	1502.91
M_{WI}	18.66	21.18	23.66	29.21	31.74	38.85	43.63	47.74	51.25	54.83	58.35
M_{YI}	1857.56	2055.88	2394.62	2527.62	2815.01	3127.74	3356.12	3425.15	3597.21	3619.35	3821.87
M_{FI}	222.68	249.16	263.27	294.15	317.45	321.09	329.52	315.23	359.45	379.71	393.85
M_{WFI}	10.27	10.82	11.15	10.31	9.52	8.02	7.15	8.21	7.47	7.75	8.54
$WECR_I$(%)	2.92	3.19	3.21	3.61	3.51	3.78	3.99	4.03	4.09	4.11	4.08

3.3. The WECR to social life of Zhengzhou

The calculation process of *WECR* to social life in Zhengzhou city is similar to that of the agricultural calculation table. The summary results of *WECR* to industry from 2005 to 2015 are shown in Table 4.

Table 4. The summary results of *WECR* to social life of Zhengzhou from 2005 to 2015. (10^{20}sej)

Item	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
M_{UL}	218.42	237.75	251.29	247.23	263.37	271.52	285.19	289.33	292.48	298.35	305.74
M_{WL}	7.21	7.35	7.27	7.39	7.75	8.61	8.74	9.13	10.07	10.35	10.94
M_{YL}	257.45	263.89	267.72	271.27	280.32	289.54	295.03	303.85	309.27	314.92	320.24
M_{FL}	109.33	129.72	133.94	135.85	130.74	127.83	132.42	131.37	128.35	119.83	115.83
M_{WFL}	1.54	1.73	1.67	1.59	1.63	1.53	1.49	1.60	1.72	1.75	1.43
$WECR_L$(%)	4.70	4.79	4.54	4.81	4.42	4.73	4.64	4.63	4.93	4.70	4.91

3.4. Result analysis

The results of *WECR* to agriculture, industry and social life of Zhengzhou from 2005 to 2015 are shown in Figure 2. From 2005 to 2015, the calculation result of *WECR* to agricultural in Zhengzhou shows an upward trend of fluctuation and the average is 8.55% in many years. Fluctuation is mainly influenced by the randomness of rainfall. In addition, due to the low solar transformity of rainfall, although the agricultural water consumption in Zhengzhou is the largest, the water resource emergy is not the highest.

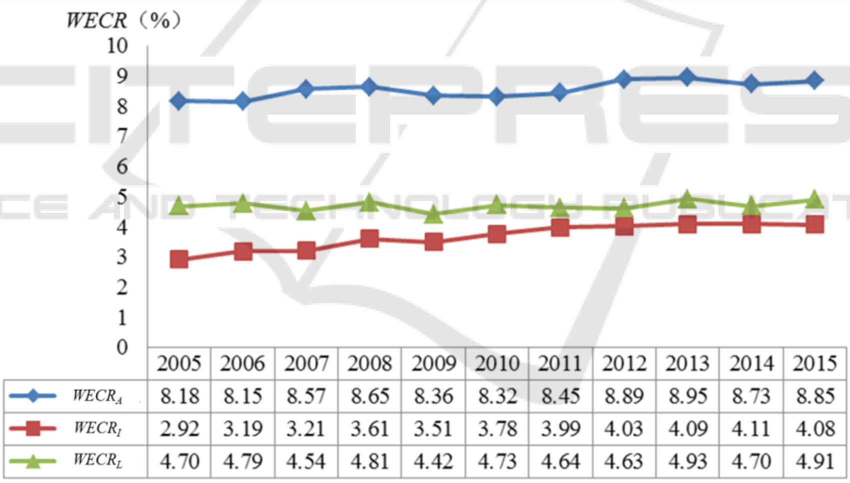

Figure 2. The trend chart of *WECR* of social economic system of Zhengzhou from 2000 to 2010.

From 2005 to 2015, the *WECR* to industry in Zhengzhou from 2005 to 2015 shows an increasing trend overall, especially since 2010, and the average is3.68%. The increasing trend is related to the implementation of new urban development policies after 2010 in Zhengzhou, such as adjusting the industrial structure, improving production processes, and improving water efficiency.

The *WECR* to social life in Zhengzhou is 4.71% in the year average. Because the contribution rate of water resources to social life is affected by many uncertain factors, such as material supply level, price level and residents' consumption capacity, there is no obvious rule to follow. However, the *WECR* to social life is relatively stable, which is basically maintained within a certain range of values and slightly fluctuated in different years.

Comparing and analyzing the law of *WECR* among different departments in Zhengzhou is: Agriculture >Social life > Industry. For agriculture, water resources are the basic material and the restrictive factors of agricultural output. Therefore, the *WECR* to agriculture is the largest. For life, water is the source of life and the basic guarantee for human survival. However, the total output emergy of social living system is less, resulting in low net contribution emergy of water resources; therefore the contribution rate of water resources in social life is low. Due to the high input of auxiliary energy and technology in the industrial system, the total emergy input is high and the emergy input of water resources is relatively low, which makes the *WECR* to industry are the lowest among the three sectors.

DING Xiangyi [11] used the production function formula of traditional economics to calculate the contribution rate of water resources (*WCR*) to *GDP* in zhengzhou in 2010. The results are shown in Table 5. Comparing the results of *WECR* and *WCR* (as shown in Table. 5), it is found that the result of *WECR* is more reasonable. Taking agriculture as an example, the *WCR* calculated by economic method is 0, which is not consistent with the facts. However, the *WECR* to agriculture in 2010 is 8.32, which considers the effect of effective rainfall and irrigation on agricultural output comprehensively, and the result is more reasonable. In addition, the *WCR* to industrial calculated by economic method is over 100%, which is obviously too large. In comparison, it is more reasonable to calculate the contribution rate of water resources in terms of emergy.

Table 5. Comparative analysis of contribution rate of water resources in Zhengzhou in 2010 by different calculation methods.

Item	agriculture	industry	social life
WCR (economic method) (%)	0	103.9	16.1
WECR (emergy method) (%)	8.32	3.78	4.73

4. Conclusions

Emergy method overcomes the defects that the currency of economic analysis methods cannot measure the contribution of nature to human economic and social development. The contribution rate of water resources calculated by emergy method is beneficial to evaluate the real benefits and contributions of water resources. Since the calculation of *WECR* involves some aspects of the socio-economic system, the transfer and transformation processes of the energy flow in the system is very complex. This paper focuses on water resources and only the energy flow that interacts with water resources is analyzed. Other ecological flows are simplified. In future research, it is necessary to conduct a systematic analysis of the energy conversion processes and interactions relationship between the energy flow, material flow and currency flow in the socio-economic system of water resources.

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