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Quantification method of water environmental value loss caused by water pollution based on emergy theory

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ABSTRACT

Water pollution is one of the main manifestations of environmental pollution. Scientific evaluation of the value loss of water environment pollution is the basis for the formulation of water environment policy. The current method of quantifying water pollution loss is economic, which makes better result relatively, but there are difficulties in quantifying social loss and ecological environmental loss. The main manifestation of water pollution is the excessive concentration of pollutants in water. Dilution is the most direct way to reduce the concentration of pollutants in water, which should be lower than standard for the treatment of water pollution. Therefore, the eco-economic value of the water resource for dilution can reflect the environmental loss of water pollution indirectly. A quantification method for the water environmental value loss caused by water pollution is established based on the ecological economics emergy theory. Taking Zhengzhou city as an example, the results showed that the average water environmental value loss caused by water pollution is as high as 5.948 billion Yuan during 2000–2015, accounting for 1.28% of gross domestic product, and indicated that the water pollution loss in Zhengzhou is serious, and its economic development is at the expense of water pollution to a certain extent. With the development of “National Water Pollution Control and Treatment Science and Technology Major Project” since 2005, the value loss of water environmental pollution in Zhengzhou has been decreasing year by year, and the water pollution treatment has achieved remarkable results.

Keywords: Water environmental pollution; Value loss; Emergy; Zhengzhou city

1. Introduction

Water pollution often leads to the decline or loss of water resources value and water environment resources value. Simultaneously, water environmental pollution may cause unforeseen effects to water, soil and ecosystems, and brings a great loss to social resources and economy [1]. In order to deal with the economic, social and ecological impacts caused by water environment pollution scientifically, the quantitative assessment of water environment value loss is necessary and critical. Nowadays, there are various methods for the calculation of water environment loss, including human capital approach [2], opportunity cost method [3], engineering cost method [4], surrogate market approach [5], replacement cost method [6], survey judgment method [7] and so on [8,9]. Comprehensive analysis indicates that the above methods for the quantification of water environment loss are based on the indirect measurement of the externalization of internal loss. These studies are not conducted directly on the concentration of pollutants in water. In addition, the current quantification of environment loss is mostly based on economic loss quantification, and does not take into consideration the economic, social and ecological loss caused by water pollution. A scientific quantitative method for the loss of water environment value is established to fully analyze the relationship between regional water pollution and economic development. It is of

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great significance to improve regional water environment and alleviate water crisis.

Zhengzhou city is located in the middle and lower reaches of the Yellow River and Huaihe River, and its surface water quality is poorer. The water quality of many rivers is inferior Grade V and their water use functions are almost disappeared [10]. In order to understand the actual water pollution status of Zhengzhou city accurately, alleviate the increasingly sharp contradiction between supply and demand of water resources, and ensure that the precious and limited water resources for sustainable economic and social development services in Zhengzhou, it is necessary to evaluate the loss of the water environment pollution in Zhengzhou scientifically and effectively. At present, the research on water pollution in Zhengzhou is mainly characterized by qualitative evaluation [11,12], and there is no quantitative research on the value loss of water environment. Therefore, according to the water environment situation in Zhengzhou, the scientific quantitative method for water environment value loss caused by water pollution is built, and the evaluation for the water environment loss in Zhengzhou is conducted.

2. Methods and materials

2.1. Water environmental value loss evaluation model

Water resources have natural, social and economic attributes. Thus, any environmental value loss evaluation should be based on the properties of water resource. According to the analysis of the water resource properties, water pollution can lead to the decrease or complete loss of water resource value and water environment resource value. The recovery of water quality can be realized through water pollutants dilution. Therefore, the ecological economic value of dilution water can be used to reflect the environmental value loss of water pollution indirectly. Based on this, emergy theory of the ecological economics is introduced into the quantification calculation of value loss of water environment, and the emergy quantification method of water environmental value loss caused by water pollution is proposed. The main steps are as follows:

2.1.1. Calculation of water resources ecological economic value based on emergy theory

Emergy theory is a new environmental economic value theory and systematic analysis method proposed by Odum [13] in the 1980s, which is widely used in quantitative research of mutual relation between human and nature, environmental resources and social economy value and so on [14].

According to the value characteristics and functional structure of water resources and its role and status in human society and river basin ecosystem, the ecological economic value of water resources is divided into three parts: economic value, social value and ecological environment value [15]. The economic value includes industrial and agricultural production value, shipping value and power value; social value includes labor value and leisure entertainment value; ecological environment value includes biodiversity conservation value, water storage value, environmental purification value, climate regulation value, transportation value, sewage loss value and sewage reclamation value. Each item of water resources emergy value can be calculated according to value characteristic and emergy theory separately, and then the ecological economic value of water resources (EMw) can be obtained by vector addition. The specific calculation method is referring to the author's previous research [15].

2.1.2. Establishing the water environmental value loss quantitative model

According to the quantification idea of water environmental value loss based on emergy theory, the ecological economic value of dilution water is taken as water environmental value loss caused by water pollution. And the value loss quantitative model of water environmental is established as follows:

$$C = \max C_i = \max \frac{(P_i - S_i - K_i \times P_i) \times W \times \text{EMw}}{S_i \times \text{EDR}} \quad (1)$$

In the formula, C is the comprehensive water environmental value loss, ￥; C_i is the water environmental value loss caused by pollutant i, ￥; P_i is the actual concentration of pollutant i, mg/L; S_i is the standard concentration of pollutant i, mg/L; K_i is the comprehensive attenuation coefficient of pollutant; W is sewage discharge, m^3; EMw is ecological economic emergy value of water resources, sej/m^3; and EDR is the emergy currency ratio of basin, sej/￥.

2.2. Description of the study area

2.2.1. Present situation of water environment in Zhengzhou city

Zhengzhou is an important central city and a comprehensive transportation hub in China. It is also a water shortage region, with a per capita water supply of 88 m^3, accounting for about 1/25 of the water per capita in the country [16]. In recent years, with the rapid growth of economic society in Zhengzhou, the water pollution is relatively outstanding, and most rivers become seasonal rivers, whose downstream tend to become a drainage channel [17].

The average surface runoff amount is 595 million m^3, and available surface water is 185 million m^3, accounting for about 31% of surface water resources in Zhengzhou. According to the surface water environment quality standard [18], the water quality category in the surface water function zone of Zhengzhou in 2015 was evaluated by comprehensive pollution index method. The water function area is a water area delineated according to the natural conditions of water resources and the current status of development and utilization to implement the corresponding water environmental quality standards. And the results showed that there were no water function zone of Grade I or Grade II, one water function zone of Grade III, three water function zones of Grade IV, six water function zones of Grade V, and eleven water function zones of inferior Grade V, as shown in Table 1.

In Zhengzhou city, the available amount of surface water resources meeting the basic water quality requirements is only 78 million m^3, just accounting for 13.1% of surface water resources. Therefore, water pollution has intensified the shortage of water resources in Zhengzhou.

Table 1
Basic status of water grades in the water function zones of Zhengzhou in 2015

Water grades[a]	Grade III	Grade IV	Grade V	Inferior Grade V	Dried-up	Total
Number of water function zone[b]	1	3	6	11	2	23
Percentage	4.4	13.0	26.1	47.8	8.7	100

[a]Water grades are classified into five categories according to the environmental function and protection target of surface water.
[b]Water function zone is a water area delineated according to the natural conditions of water resources and the current status of development and utilization to implement the corresponding water environmental quality standards.

3. Results and discussion

3.1. Emergy calculation of water resources ecological economic value in Zhengzhou

In combination with the actual situation of water–ecological–economic system in Zhengzhou, the water resources ecological economic value of Zhengzhou in 2000, 2005 and 2010–2015 were calculated by emergy theory of the ecological economics. The data for calculating required, water quality data are from the "Bulletin of Environmental Status of Zhengzhou City", the social and economic data are from "Zhengzhou Statistical Yearbook".

The results are shown in Fig. 1, which show that the trend of water resources ecological and economic value is raising volatility. The water resources ecological economic value of Zhengzhou in 2015 was 9.7 Yuan/m^3, while the price of residential water and non-residents water was 3.9 and 5.2 Yuan/m^3, respectively. The comparison and analysis indicate that the monetary value of water resource calculated by emergy theory is greater than water price in the same period, the main reason is that the resource value, development and utilization cost, social economy contribution and ecological environment effect of water resources are considered in the calculation process, which can reflect the true value of water resources more comprehensively. Therefore, the quantification method of water environmental value loss based on emergy theory can reflect the economic, social and ecological environmental impact caused by water pollution more truly.

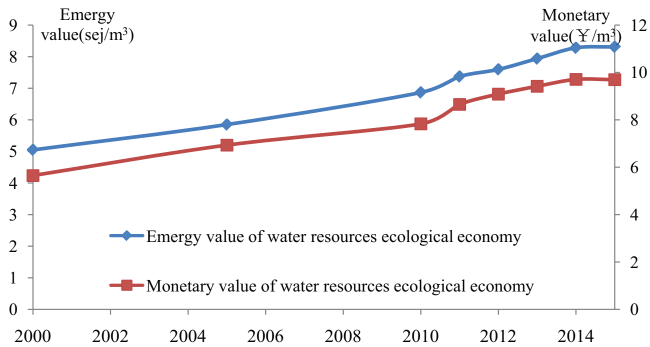

Fig. 1. The emergy results of water resources ecological economic value of Zhengzhou.

3.2. Quantification of water environmental value loss of Zhengzhou

According to the surface water quality test results, the main pollutants of water environment in Zhengzhou were chemical oxygen demand (COD) and NH_3-N. Based on the surface water environment quality standard [18], the water quality standard of key pollutant dilution of Zhengzhou was determined, then the water environmental value loss caused by water pollution of Zhengzhou in 2000, 2005 and 2010–2015 were calculated, respectively, as shown in Table 2. Among them, the comprehensive degradation coefficient of the pollutant is based on "The technical key points of surface water's environmental capacity" [19], k = 0.1. In Table 2, the water environmental value loss is equal to the outsourcing value of the pollutant discharge value loss of COD and NH_3-N.

3.3. Analysis of accounting results

The comparison results in Fig. 2 showed that the water pollution condition in 2000 and 2005 was relatively serious, and the whole condition has improved markedly since 2010. In 2000, NH_3-N exceeded 4.8 times, while COD exceeded 3.1 times. In 2005, NH_3-N exceeded 5.2 times, while COD exceeded 4.1 times. From 2010 to 2015, NH_3-N only exceeded 2.2 times, COD only exceeded 0.4 times. Furthermore, the pollutant concentration indicated that the excessive multiples of NH_3-N were greater than COD. And the dilution water of NH_3-N was more than COD. It showed that NH_3-N is the key pollutant and the main factor of water environment value loss of Zhengzhou.

In Fig. 3, the results of water environmental value loss of Zhengzhou city showed a trend of rising first and then decreasing. The peak appeared in 2005, the loss as high as 15.224 billion Yuan, accounting for about 9.17% of gross domestic product (GDP) (see Table 2). During the period from 2000 to 2015, the loss of water environmental value in Zhengzhou averaged 59.48 billion Yuan, or 1.28% of GDP. The results showed that water environment value loss caused by water pollution of Zhengzhou city was bigger. The main reasons are as follows: (1) Zhengzhou is a city of severe lack of water resources. Water shortage and pollution is very outstanding. (2) The source of agricultural pollution is serious and difficult to govern. At present, the complexity and severity of the relative industrial pollution of the agricultural surface to water pollution have been recognized and valued by all countries [20]. Excessive use of fertilizers and pesticides in agricultural production leads to a large number of chemical fertilizers with the return farmland water into the river, causing eutrophication of water bodies. In addition, the extensive use of chemical fertilizers has reduced the use of livestock and poultry waste in rural areas, and a large number of livestock and poultry droppings have not been disposed in the river. These are the main factors leading to the excessive of NH_3-N in rivers. (3) With the development of social economy,

Table 2
The value loss of water environment pollution of Zhengzhou city

Control section	Pollutants	Measured concentration[a] (mg/L)	Water quality standards[b] (mg/L)	Dilution water (m^3)	water resources ecological economic value (￥/m^3)	Pollutant discharge value loss (10^8 ￥)	water environmental value loss (10^8 ￥)	The share of GDP (%)
2000	NH_3-N	8.63	1.5	4.18	5.65	33.54	33.54	4.60
	COD	122	30	2.66		21.35		
2005	NH_3-N	9.24	1.5	4.54	6.93	152.24	152.24	9.17
	COD	153	30	3.59		120.28		
2010	NH_3-N	6.51	1.5	2.91	7.83	83.31	83.31	2.07
	COD	51	30	0.53		15.19		
2011	NH_3-N	6.12	1.5	2.67	8.65	67.59	67.59	1.36
	COD	47	30	0.41		10.37		
2012	NH_3-N	5.56	1.5	2.34	9.09	83.59	83.59	1.52
	COD	38	30	0.14		5.01		
2013	NH_3-N	3.23	1.5	0.94	9.42	25.39	25.39	0.41
	COD	42	30	0.26		7.04		
2014	NH_3-N	4.85	1.5	1.91	9.71	24.54	24.54	0.36
	COD	44	30	0.32		4.11		
2015	NH_3-N	2.48	1.5	0.49	9.70	5.66	5.66	0.08
	COD	38	30	0.14		1.62		

[a]Measured concentration is the actual concentration of pollutants observed from water samples.
[b]Standard concentration is the concentration of pollutants specified in the surface water environment quality standard [18].

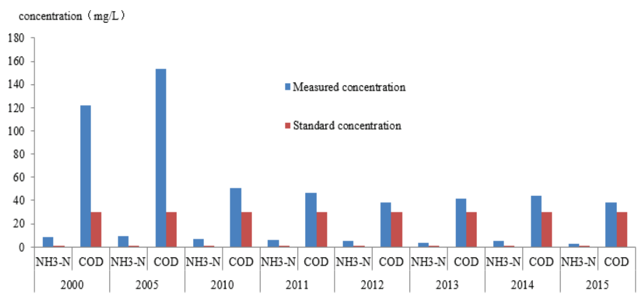

Fig. 2. The comparison between measured concentration and standard concentration of the key pollutants in Zhengzhou.

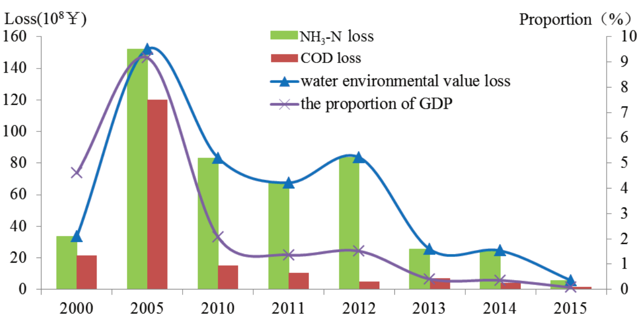

Fig. 3. The value loss of water environment pollution and its proportion of GDP in Zhengzhou.

people's living standards increase year by year, and the load of domestic sewage pollution increases accordingly.

With the implementation of "The National Water Pollution Control and Treatment Science and Technology Major Project", after 2005, the investment of water pollution treatment increased gradually. The water environment was improving year by year, so the environment value loss caused by water pollution was gradually reduced. The proportion to GDP was reduced from 9.17% in 2005 to 0.08% in 2015. Zhengzhou has made remarkable progress in water pollution control.

In 2010, Lv and Ling [21] calculated the economic loss of water pollution in Zhengzhou from 2000 to 2005 using the economic loss function of water environment pollution. The results showed that the economic loss of water pollution of Zhengzhou in 2000 and 2005 was 21.79 and 100.87 billion Yuan, respectively, accounting for 2.95% and 6.07% of GDP, respectively. Compared with the calculation results of this study, the calculation results of the economic loss function method of water environment pollution are small. This indicates that the emergy quantification method of water environment value loss proposed in this study considers not only the economic loss of water pollution but also the social loss and ecological environment loss comprehensively. Therefore, emergy theory provides a more comprehensive quantitative method for evaluating the loss of water environment caused by water pollution.

4. Conclusions

Based on the emergy theory of ecological economics, the eco-economic value of the water resource for dilution reflects the environmental value loss caused by water pollution indirectly, and an emergy quantification method of water environment value loss is proposed in this study. The results of value loss of water environment pollution of Zhengzhou in 2000, 2005 and 2010–2015 indicate a trend of rising first and then decreasing. And the average annual loss is 5.948 billion

Yuan, accounting for about 1.28% of GDP per year. This suggests that much of Zhengzhou's economic growth comes at the cost of water pollution. With the implementation of "The National Water Pollution Control and Treatment Science and Technology Major Project", the water environmental value loss of Zhengzhou city has reduced gradually.

The quantification of the value loss of water environment caused by water pollution is a very complicated scientific problem. Limited by the knowledge level and the research time, although the loss of the functional value of water pollution was studied, only the recovery of key pollutants was considered in the quantification process, and the impact of other pollutants on water quality was ignored so that the considerations were not comprehensive enough. In the future, more comprehensive analysis of the factors, affecting the value loss of water pollution, should be analyzed, and more complex and comprehensive quantitative methods can be constructed to obtain more scientific research results.

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