RESEARCH ARTICLE

Study on the quantification of ecological compensation in a river basin considering different industries based on water pollution loss value

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Abstract

The study on the quantification of ecological compensation (eco-compensation) in a river basin can help to make environmental protection more compatible with ecological construction. In this paper, the upstream and downstream of the river basin were treated as the subjects and objects of eco-compensation, and the mechanism of eco-compensation was clarified. The emergy analysis theory (EMA) was used to calculate the values of water resources in sub-industries (agriculture, industry, life, and recreation). The pollution loss rate theory (PLR) was adopted to calculate the water pollution loss rate in sub-industries. According to the value of water resources and pollution loss rate in sub-industries, combined with the water consumption of sub-industries in the river basin, the Ecological Compensation Quantification Model of Sub-industries (ECQ-Is Model) was constructed. Under the guidance of the aforementioned theory and model, a comprehensive research was conducted on the Xiaohong River. The results showed that the eco-compensation values of the upstream area, industry, and agriculture in the river basin were higher. Therefore, it is essential that the water resources in the Xiaohong River basin be well conserved and managed. In addition, the research results point out the direction for water pollution control, which includes promoting the coordinated development of the upstream and downstream, and maximizing the ecological benefits of the river basin.

Keywords Ecological compensation · Quantification model · Emergy analysis theory · Pollution loss rate · Value of water resources · Xiaohong river basin

Introduction

In recent years, with the large-scale development and utilization of water resources, water pollution and the degeneration and destruction of water ecosystem have become important factors hindering global socioeconomic development. The eco-environmental problems in river basins have an effect on all aspects of human production and life. As an emerging means of ecological protection, the eco-compensation of river basins can better coordinate the interests of human and water resources, and maintain the balance between the development and utilization of water resources and ecological protection. Thus, it plays an increasingly important role in the management of water resources. The eco-compensation mechanism can help to solve the scarcity of water resources and severe water pollution, and effectively protect water resources and the eco-environment as well as coordinate ecological development. Thus, eco-compensation mechanism can promote sustainable, coordinated, and healthy development of economy, society and ecology in the basin, and is of great significance to the reasonable use and distribution of water resources, as well as the sustainable economic development of the basin.

In the aspect of eco-compensation research, eco-compensation usually refers to the payment of environmental service (PES), which means the exchanges of the value of environmental services between enterprises, farmers, or governments. It is based on clear property rights and low transaction costs (Hayes et al. 2015; Murtinho and Hayes 2017). Eco-compensation is also a practice, a means by which the

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negative impacts brought by economic development are offset by active measures to protect the environment (Brown et al. 2014). Studies on the service function of ecosystem or the environment began to emerge in the 1960s. In 1963, Davis first applied the conditional value assessment method to studying the recreational value of a forest in Maine, USA. Since then, the method has been used to estimate the recreational and esthetic value of environmental resources in the development of eco-compensation (Burgin 2008; Bull et al. 2013). In 1977, Westman proposed the concept of "natural service" and the issue of value assessment (Böck et al. 2015). In the same year, the publication of "The Natural Service Society's Dependence on Natural Ecosystem" (Aretano et al. 2015) edited by Daily marked that the research on the value assessment of ecosystem services had become a hot spot and frontier of ecology and ecological economics. China's State Council issued the "Outline of Ecological Protection" in 2000, and proposed the eco-compensation system for the first time. Costa Rica enacted the Forest Act, which demanded that the National Forest Fund should negotiate with the eco-compensation payers. The two parties signed a compensation contract, and eco-compensation was carried out according to the contract (Pagiola 2006). With the establishment of eco-compensation systems, eco-compensation measures have begun to be implemented globally. However, the development of eco-compensation mechanism is in an immature stage, in which the government has a dominant position, and the combination with the market mechanism is found wanting.

With the widespread implementation of the eco-compensation mechanism, the means of eco-compensation and quantification methods become more and more diversified. At present, the eco-compensation framework mainly includes direct one-to-one transaction, market compensation, regional cooperation, and public compensation (Sun et al. 2013). In these methods, the relationship between the participants is distinct, and the supply and demand relationship between the compensator and the compensated is clear. Besides, the system is relatively complete, with strict monitoring and enforcement mechanisms, and a transparent national standard certification system. Currently, these compensation methods have been used in many countries around the world, including New Zealand, Costa Rica, Australia, and Italy (Brown et al. 2014; Ross and Cody 2016; Rijke et al. 2013; Rega and Carlo 2013). In regard to the research on quantification method of river basin eco-compensation, present studies mostly focus on measures to compensate for the impact of human behaviors on the water quality in the river basin, because the global river basin presents a situation in which the quality-induced water shortage is more serious than the quantity-induced water shortage. The quantification methods of water quantity eco-compensation are generally based on water rights and the contribution to the GDP of the whole river basin (He et al. 2015). Concerning the quantification methods of water quality eco-compensation, the

approach of ecological restoration cost (Brancalion et al. 2014) and the method of water quality and water quantity correction coefficient (Liu et al. 2017) are generally adopted. The reducing quantity of pollutants (Marleni et al. 2015) and the water quality of the cross-boundary section which fails to meet the standards are also taken into account (Noerfitriyani et al. 2018). All of the above methods have limitations, and can only be applied locally within a reasonable range, and there is no uniform quantitative standard (Haiying and Guihua 2015). In the process of quantitative research on eco-compensation in the future, the global applicability, rationality, and operability of eco-compensation quantitative standards should be the key content. At present, there are few studies on the eco-compensation value of river basin using EMA combined with PLR. EMA is generally used for studying the eco-compensation of agricultural cultivated land. In recent years, the eco-compensation value of river basin can also be calculated through the correspondence between emergy and economic value, but it does not take into consideration the water pollution status of the river basin. In relative terms, the river basin eco-compensation system and ways of compensation are too general. It lacks the division of the subject and object of compensation according to the upstream and downstream areas, and it cannot reflect in detail the compensation relationship between the related subjects and objects—the diversified industries and occupations in regions along the upstream and downstream of the river basin.

The study of eco-compensation in a river basin considering different industries can help to make the interests of different regions more compatible with industries, and maximize the benefits of river basin eco-compensation. This paper constructed the eco-compensation quantification model of sub-industries (ECQ-Is Model) based on PLR and EMA at river basin level, which included the value of water resources in sub-industries module (WRV-Is Module), pollution loss rate in sub-industries module (PLR-Is Module), and eco-compensation value in sub-industries module (ECV-Is Module). So this paper took Xiaohong river basin as an example to carry out a comprehensive research. In the study, the values of water resources, pollution loss rate, and eco-compensation value of agriculture, industry, life, and recreation in the Xiping, Shangcai, Pingyu, and Xincai counties in the upstream and downstream of the Xiaohong River Basin from 2012 to 2015 were calculated. Finally, the eco-compensation results of Xiaohong River Basin were analyzed from time, space, and industry scales and capital flow. The research results are expected to provide new theories and new models for the study of eco-compensation at river basin level.

Study area and data

This paper conducted case studies on the Zhumadian section of the Xiaohong River Basin in China. The upstream and

downstream of the river basin were treated as the subjects and objects of eco-compensation, and the study on the quantification of eco-compensation in the river basin was conducted. The Xiaohong River originated from Funiu Mountain in Wugang City, Henan Province, flowing through Wuyang County, Luohe City, Xiping County, Shangcai County, Pingyu County, and Xincai County, Zhumadian City. The Xiaohong River and the Ru River meet at the Xincai Bantai and enter the Hong River, which belongs to the secondary tributary of the upstream of the Huai River. The main stream of Xiaohong River is 251 km long with a basin area of 4,287 km² (Fig. 1). The Huai River is one of the key points of water pollution control in China (Shi et al. 2016). The increasingly serious water pollution of Hong River has become a limiting factor for the sustainable development of the river basin, and the emission of pollutants exceeding the standard concentration seriously affects the ecological environment (Shaofei et al. 2015). In this paper, the pollution loss value was determined by the PLR combined with EMA, and then the eco-compensation value of the river basin was obtained. The data comes from the Zhumadian Statistical Yearbook, the Zhumadian Water Resources Bulletin, the Henan Province Water Conservancy Statistical Yearbook, and the Henan Provincial Environmental Monitoring Center.

Methods

This paper constructed the ECQ-Is Model based on EMA and PLR, which included the WRV-Is Module, the PLR-Is Module, and the ECV-Is Module. In the WRV-Is Module, based on the EMA, the emergy analysis table of the system was drawn, and the energy and emergy network of the system were established.

On this basis, the calculation methods of emergy conversion rate and water resource contribution rate were obtained, and the values of water resources in agriculture, industry, life, and recreation were calculated respectively. Through this module, the economic value brought by each cubic meter of water in the basin was obtained, and the economic development level of each industry was understood. In the PLR-Is Module, representative pollutants were selected, and the mathematical function of pollution concentration-value loss was established by analyzing the functional relationship between pollutant emissions and value loss. The pollution loss rates in agriculture, industry, life, and recreation were calculated, respectively. Through this module, it was possible to know the pollution loss caused by the pollutants generated in the upstream areas of various industries in the basin to the water resources in the downstream areas, and to analyze the pollution discharge status and pollution control capacity of different industries in various regions. In the ECV-Is Module, based on the value of water resources and the pollution loss rate in sub-industries, the eco-compensation values in agriculture, industry, life, and recreation were quantified respectively. Through this module, the eco-compensation value of upstream region to downstream region was determined. The problems of river basin water pollution and environmental protection were discussed comprehensively to provide theoretical basis for the implementation of river basin eco-compensation mechanism. The first two modules calculated the value of water resource and pollution loss rate based on the emergy of water resource and pollutant concentration of various industries in the basin, and the third module calculated the pollution loss value by combining the two, and finally determined the eco-compensation value of different industries based on the water consumption of different industries. The model is applicable to river basin where pollution is more serious and eco-compensation mechanisms are implemented (Fig. 2).

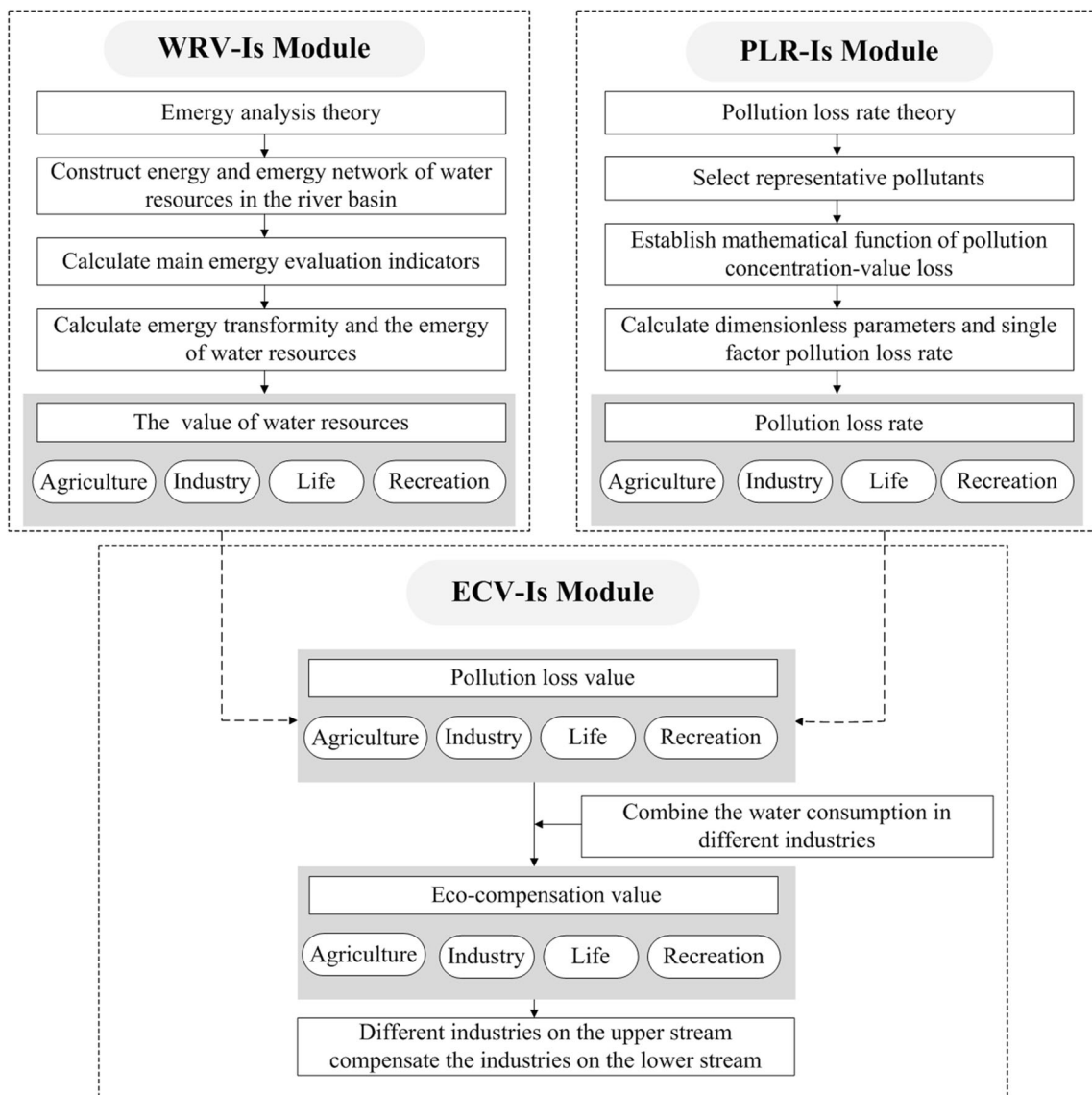Fig. 1 The profile map of Xiaohong River
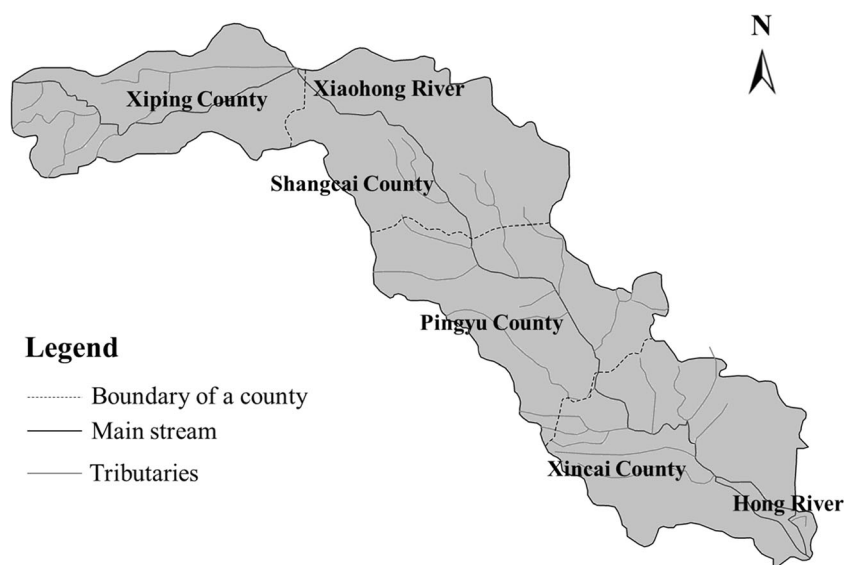
Fig. 2 The structure diagram of the ECQ-Is Model

The WRV-Is Module based on the emergy analysis theory

The EMA was proposed and developed by scientists headed by the famous American ecologist Odum in the late 1980s (Odum 1996). Emergy is a new concept in the ecological economics that measures the products and processes of natural systems and economic systems (Campbell 2010). The value of water resources can be defined as the function and utility of water resources in supporting and maintaining the existence and operation of the eco-economic system. It is accompanied by the circulation and flow of water resources in the eco-economic system, and manifested in eco-economic functions such as products, labor services, maintaining of ecological balance, improving of social welfare, and purifying of sewage waste. According to the basic principle of emergy analysis, the analysis of the value of water

resources is to collect data of water resources in different industries, analyze energy flow and emergy conversion process of different industries, establish energy and emergy network, and calculate relevant emergy indicators. Then, the emergy conversion rate is calculated according to the characteristics and formation process of different stages and different water bodies in the water cycle. Finally, the values of water resources in sub-industries are calculated according to the utilization of water resources (Lv 2009).

Regarding water resource recycling systems as energy systems, the original data of energy flow, material flow, and currency flow in the river basin were collected. From an overall perspective, the interaction, mutual influence, and emergy conversion relationship between water cycle and other logistics and energy flow were analyzed. The energy and emergy network of the water resources in the river basin was constructed (Fig. 3).
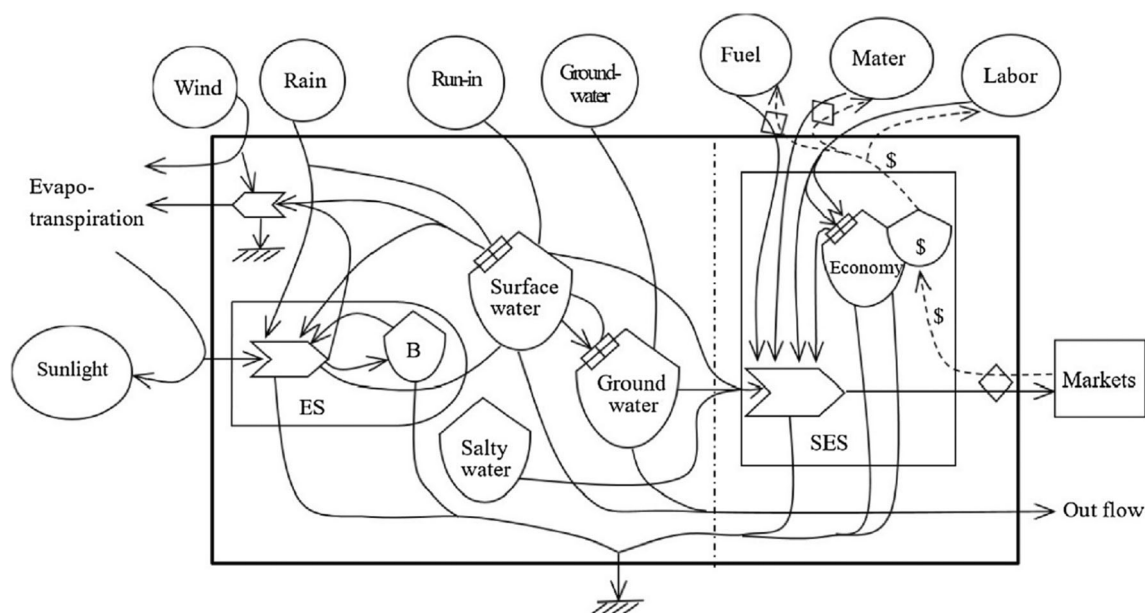
Fig. 3 The energy and emergy network of water resources in the river basin (ES, ecological system; SES, social and economic system; B, biology, Mater, materials; Labor, labor service)

Emergy evaluation indicators

The emergy of the eco-economic system comes from the emergy of natural resources in the region, including sunlight, wind energy, rainwater chemical energy, industrial and agricultural imports, and energy and material products. The system output refers to all the outputs of the entire region, including products of life, industry, and agriculture. The symbols and meanings of main emergy evaluation indicators of water resource eco-economic systems in river basin are shown in Table 1.

Calculation methods of the value of water resources in sub-industries

The values of water resources in industrial and agricultural systems reflect the contribution of water as a production factor in industrial and agricultural economic activities. They can be

calculated by the contribution rates of industrial and agricultural production systems multiplying the corresponding output emergy. The value of water resources in living systems can be calculated by the contribution rate of living system multiplying the living output emergy and Engel coefficient. The value of water resources in recreation system can be calculated by the revenue from tourism multiplying the emergy-currency ratio and the proportion of water tourism in the current year. The specific calculation processes are shown in Table 2.

The PLR-Is Module based on the pollution loss rate theory

The loss of water pollution can directly reflect the impact of drainage on water environment and economic society, and also reflect the objective facts of economic losses caused by water pollution in the river basin. When pollutants enter the

Table 1 Main emergy evaluation indicators of sub-industries in river basin

Indicator	Symbol	Meaning
Updateable environment resources	ER	Renewable energy, including the energy of solar, wind, rain, earth rotation
Unable to update environmental resources	EN	Non-renewable energy or products, including land loss and industrial products such as crude oil
Total emergy input	EI	Total emergy of the system input
Total emergy output	EO	Total emergy of the system output
Emergy-currency ratio	P	The development and modernization level of the system resource
Emergy-currency value	V	A currency quantity equal to the emergy
Emergy transformity	τ	The amount of solar emergy per unit of water
Contribution rate of water resources	WCR	The ratio of water emergy input to total emergy input

Table 2 The contribution rate and value of water resources in sub-industries

Item	Symbol or formula	Unit
W_A, W_I, W_L, and W_R are water consumptions in agriculture, industry, life, and recreation.	W_A, W_I, W_L, W_R	m³
WUE_A, WUE_I, and WUE_L are the emergy of water consumptions in agriculture, industry, and life.	WUE_A, WUE_I, WUE_L	sej
EI_A, EI_I, and EI_L are the total input emergy in agriculture, industry, and life.	EI_A, EI_I, EI_L	sej
EO_A, EO_I, and EO_L are the total output emergy in agriculture, industry, and life.	EO_A, EO_I, EO_L	sej
WCR_A, WCR_I, and WCR_L are the contribution rates of water resources in the agriculture, industry, and life.	$WCR_A = WUE_A/EI_A$ $WCR_I = WUE_I/EI_I$ $WCR_L = WUE_L/EI_L$	%
M_A, M_I, M_L, and M_R are the emergy of water resources in the agriculture, industry, life, and recreation. E is the Engel coefficient, TI is the revenue from tourism, and η is the proportion of water tourism.	$M_A = WCR_A \times EO_A$ $M_I = WCR_I \times EO_I$ $M_L = WCR_L \times EO_L \times E$ $M_R = TI \times \eta \times P$	sej
V_A, V_I, V_L, and V_R are the values of water resources in agriculture, industry, life, and recreation.	$V_A = M_A/P$, $V_I = M_I/P$ $V_L = M_L/P$, $V_R = M_R/P$	¥
EP_A, EP_I, EP_L, and EP_R are the values of per cubic meter of water resources in the agriculture, industry, life, and recreation.	$EP_A = V_A/W_A$, $EP_I = V_I/W_I$, $EP_L = V_L/W_L$, $EP_R = V_R/W_R$	¥/m³

¥ stands for CNY (Chinese Yuan), usually referring as RMB (Ren Min Bi)

water body, the normal function of the water body will decrease or be lost, further reducing the output and quality of different industries closely related to the water body (Hu et al. 2014). James (1974) advanced a loss-concentration curve, also known as the James curve. It pointed out that water quality is deteriorating during use and transportation, and the value of water resources would be reduced. The ratio of the loss of water value caused by a certain pollutant to the total value of water is defined as the pollution loss rate of the pollutant to the water body. On the basis of the loss of water value of a single pollutant, the pollution loss rate caused by the comprehensive pollutant can be obtained.

In the ecological environment, the pollution concentration of water in different industries are $c_{i,j}$ ($i = 1$ to n, n represents the number of pollutants; $j = 1$ to m, m represents the number of industries). The ratio of the economic loss $S_{i,j}$ caused by water pollution in different industries to the value $K_{i,j}$ of the polluted water is the water pollution loss rate in different industries, and called single factor pollution loss rate, expressed as:

$$R_{i,j} = \frac{S_{i,j}}{K_{i,j}} = \frac{1}{1 + a_{i,j}\exp\left(-b_{i,j}C_{i,j}\right)} \quad (1)$$

where $a_{i,j}$ and $b_{i,j}$ are the dimensionless parameters, which are determined by the self-characteristics of pollutants, and can be estimated by combining pollutant discharge limits with water quality standards. $C_{i,j} = c_{i,j}/c_{0i,j}$, and $c_{0i,j}$ are the concentrations of a certain pollutant allowed in the environment of different industries, and are determined

according to the water quality standards of each country (mg/L), which are expressed as:

$$a_{i,j} = \frac{K_{i,j}}{S_{0i,j}} - 1 \quad (2)$$

$$b_{i,j} = r \times c_{oi,j} \quad (3)$$

where $S_{0i,j}$ are the critical values causing pollution loss in different industries, and r is the proportional coefficient.

For a variety of pollutants, the comprehensive pollution loss rate expression is:

$$R_j^{(i)} = R_j^{(i-1)} + \left(1 - R_j^{(i-1)}\right) \times R_{i,j} \quad (4)$$

where $R_j^{(i)}$ is the comprehensive pollution loss rate of i species of pollutants in the j industry, and $R_{i,j}$ is the pollution loss rate of the pollutant i in the j industry.

The ECV-Is Module

According to the value of per cubic meter of water resources in sub-industries, combined with the comprehensive pollution loss rate of sub-industries, the pollution loss value of water resources in sub-industries can be calculated. Finally, the eco-compensation value of the sub-industries is calculated according to the water consumption of sub-industries. The eco-compensation value of the basin refers to the compensation of the water ecological function and the value of water resources in the basin, including compensation to units or individuals, who pay for the protection and

restoration of the ecological environment and its functions. Expressed as:

$$C_A = R_A^{(i)} \times \mathrm{EP}_A \times Q_A \tag{5}$$

$$C_I = R_I^{(i)} \times \mathrm{EP}_I \times Q_I \tag{6}$$

$$C_L = R_L^{(i)} \times \mathrm{EP}_L \times Q_L \tag{7}$$

$$C_R = R_R^{(i)} \times \mathrm{EP}_R \times Q_R \tag{8}$$

where C_A, C_I, C_L, and C_R are the ecological compensation values of agriculture, industry, life, and recreation respectively, ¥. $R_A^{(i)}$, $R_I^{(i)}$, $R_L^{(i)}$, and $R_R^{(i)}$ are the comprehensive pollution loss rates of i pollutants in agriculture, industry, life, and recreation respectively. Q_A, Q_I, Q_L, and Q_R are the water consumptions of agriculture, industry, life, and recreation respectively, $10^8 \mathrm{m}^3$.

Results

The value of water resources in sub-industries

According to Table 1, the emergy evaluation indicators of the water resources eco-economic system in the Xiaohong River Basin of Zhumadian from 2012 to 2015 were calculated as shown in Table 3.

Based on the actual situation and relevant data of Xiaohong River Basin, the paper analyzed the relationship between the main currency flows of water resources and corresponding industries, and calculated the emergy of water resources in sub-industries. The emergy of water resources in agricultural system, industrial system, living system, and recreational system in the Xiaohong River Basin was summarized. The specific results are shown in Table 4.

The emergy-currency ratio and water consumption of sub-industries were used to convert the emergy of water resources in sub-industries into the value of per cubic meter of water resources in corresponding industries. The specific results are shown in Table 5.

The pollution loss rate in sub-industries

According to the water resources bulletin of Zhumadian from 2012 to 2015, the water quality of the Xiaohong River Basin

Table 4 The emergy of water resources in sub-industries (10^{20}sej)

Industry	2012	2013	2014	2015
Agriculture	79.63	60.73	34.61	38.29
Industry	38.12	43.13	32.63	29.68
Life	5.59	6.22	5.49	4.37
Recreation	17.42	22.58	26.87	33.15

was poor, and industrial pollutants such as chemical oxygen demand (COD) and ammonia nitrogen (NH$_3$–N) had a greater impact on water bodies. In addition, as a typical agricultural county, Zhumadian had become increasingly polluted by agricultural pollution, and the total phosphorus (TP) of agricultural water pollution had also become a major pollutant affecting water bodies. Therefore, this paper selected COD, NH$_3$–N, and TP as typical pollutants, and gathered the statistics of annual average of three pollutants in various industries. The statistics of pollutants in agricultural and recreational systems are point source, and the statistics of pollutants in industrial and living systems are surface source.

According to the loss-concentration curve, only when the pollution in the water reaches a certain level, the value of water resources will be lost (Mianhao 2015). The background concentration is usually used as the starting point for the pollution loss. When the concentration of the pollutant reaches the background concentration, the pollution loss rate of the water resources is assumed to be 0.01 (Phuong and Gopalakrishnan 2003). The critical concentration of serious pollution is used as the end point of pollution loss. When the concentration of pollutant reaches the critical concentration of serious pollution, the pollution loss rate of the water resources is assumed to be 0.99. Due to the difficulty in data collection, according to the relevant research results, the water quality targets of local different industries are generally used as the background concentration, and the critical concentration of serious pollution can be determined by referring to the relevant provisions of the national comprehensive pollutant discharge standards. Thus, the background concentration $c_{i,j}$ of each pollutant in sub-industry and the critical concentration $c_{0i,j}$ of severe pollution could be obtained, and parameters $a_{i,j}$ and $b_{i,j}$ were approximated by combining Formulas (2) and (3). The specific results are shown in Table 6.

According to the parameters $a_{i,j}$ and $b_{i,j}$ of pollutants in sub-industries, the pollution loss rate of each pollutant in the

Table 3 Main emergy evaluation indicators of sub-industries in Xiaohong River Basin

Emergy indicator	2012	2013	2014	2015
Updateable environment resources (10^{20}sej)	20.33	22.18	29.00	21.86
Unable to update environmental resources (10^{20}sej)	247.03	357.49	401.48	440.89
Total emergy (10^{20}sej)	2893.90	3338.96	3533.25	3669.12
GDP (10^{11}¥)	2.22	2.55	2.81	2.90
Emergy-currency ratio (10^{11}sej/¥)	20.86	21.65	20.51	20.30

Table 5 The value of per cubic meter of water resources in sub-industries (¥/m³)

Industry	2012	2013	2014	2015
Agriculture	3.47	3.78	3.43	3.40
Industry	9.08	9.89	9.83	8.47
Life	5.21	4.71	4.36	3.63
Recreation	0.60	0.97	1.53	1.51

Table 7 Comprehensive pollution loss rate of sub-industries in four counties

Time	County	Comprehensive pollution loss rate			
		Agriculture	Industry	Life	Recreation
2012	Xiping	0.03	0.05	0.07	0.03
	Shangcai	0.08	0.09	0.15	0.07
	Pingyu	0.02	0.03	0.06	0.02
	Xincai	0.02	0.02	0.03	0.02
2013	Xiping	0.03	0.05	0.05	0.04
	Shangcai	0.05	0.06	0.10	0.05
	Pingyu	0.03	0.03	0.09	0.03
	Xincai	0.02	0.03	0.04	0.02
2014	Xiping	0.05	0.06	0.07	0.05
	Shangcai	0.04	0.04	0.09	0.04
	Pingyu	0.03	0.04	0.06	0.03
	Xincai	0.02	0.04	0.04	0.03
2015	Xiping	0.03	0.06	0.05	0.04
	Shangcai	0.02	0.03	0.05	0.02
	Pingyu	0.02	0.03	0.04	0.02
	Xincai	0.02	0.03	0.04	0.02

four counties of the river basin from 2012 to 2015 could be calculated by Formula (1) combined with the measured data. According to Formula (4), the comprehensive pollution loss rate was determined. The specific results are shown in Table 7.

The eco-compensation value in sub-industries

The eco-compensation value was determined according to the amount of pollution loss. By combining the calculation results of the value of per cubic meter of water resources and the comprehensive pollution loss rate of sub-industries in the river basin, the pollution loss value of per cubic meter of water resources in sub-industries in four counties could be obtained. The specific results are shown in Table 8.

By combining the water consumption of sub-industries in the Xiaohong River Basin, the eco-compensation value of each industry in each county was calculated. The specific results are shown in Table 9.

Discussion

Feasibility study on the value of water resources

The value of water resources and water prices are different but related concepts. Water pricing is a measure of the relationship between the sale and purchase of water as a commodity in a market economy. It is the amount of money that the user should pay the operator for the purchase of per

Table 6 Parameters $a_{i,j}$ and $b_{i,j}$ in sub-industries

Industry	Parameter	COD	NH₃–N	TP
Agriculture	$a_{i,1}$	407.71	191.00	145.25
	$b_{i,1}$	1.42	0.66	0.38
Industry	$a_{i,2}$	178.10	160.67	502.05
	$b_{i,2}$	0.59	0.48	1.62
Life	$a_{i,3}$	623.39	135.96	145.25
	$b_{i,3}$	1.84	0.32	0.38
Recreation	$a_{i,4}$	220.33	191.00	987.52
	$b_{i,4}$	0.80	0.66	2.30

cubic meter of water (Schoengold and Sunding 2014). The appropriate position of water price in macro-price system is determined by means of resource accounting and economic accounting. Water pricing is based on the assessment result of the value of water resources (Rupérez-Moreno et al. 2015).

According to Table 5, water price and value of water resources in the research area were analyzed and compared. By collecting the data of per capita disposable income of residents, per capita water expenditure, and annual per capita water consumption, this paper analyzed the proportion of water expenditure in the per capita disposable income of residents in the research area. The specific results are shown in Table 10.

According to the research of the World Bank and relevant international lending institutions, the internationally accepted sustainability standards for developing countries are as follows: 3 to 5% of the per capita disposable income of residents (Chunling et al. 2015). Regarding the current proportion of per capita water expenditure in per capita disposable income of residents, the figures from 2012 to 2015 are 0.56%, 1.8%, 1.9%, and 1.7%, respectively, which are far from the standard range of 3 to 5%, indicating that the water price in the area is low. Taking 2015 as an example, the water price of 3% affordability was 17.02 ¥/m³, close to the value of water resources, which is 17.01 ¥/m³ according to the result of calculation in this paper. It verifies the result of the calculation of water resources value presented in this paper and proves the feasibility of the method.

Table 8 Pollution loss value of per cubic meter of water resources in sub-industries in four counties (¥/m³)

Time	County	Pollution loss value of per cubic meter of water resources			
		Agriculture	Industry	Life	Recreation
2012	Xiping	0.10	0.45	0.36	0.02
	Shangcai	0.28	0.82	0.78	0.04
	Pingyu	0.07	0.27	0.31	0.01
	Xincai	0.07	0.18	0.16	0.01
2013	Xiping	0.11	0.49	0.24	0.04
	Shangcai	0.19	0.59	0.47	0.05
	Pingyu	0.11	0.30	0.42	0.03
	Xincai	0.08	0.30	0.19	0.02
2014	Xiping	0.17	0.59	0.31	0.08
	Shangcai	0.14	0.39	0.39	0.06
	Pingyu	0.10	0.39	0.26	0.05
	Xincai	0.07	0.39	0.17	0.05
2015	Xiping	0.10	0.51	0.18	0.06
	Shangcai	0.07	0.25	0.18	0.03
	Pingyu	0.07	0.25	0.15	0.03
	Xincai	0.07	0.25	0.15	0.03

Analysis of eco-compensation value of sub-industries in the river basin

According to the eco-compensation value of each industry in each county, the change trend of the eco-compensation value of each industry in the four counties was drawn as shown in Fig. 4.

From a chronological perspective, the eco-compensation value of the Xiaohong River Basin in 2012~2014 showed a trend of gradual growth in general, except the decline in 2015. In November 2013, China proposed the plan of "accelerating the construction of ecological civilization system," including the implementation of eco-compensation (Wang 2014). The implementation of the eco-compensation mechanism in 2014 contributed to the decline of eco-compensation value in the Xiaohong River Basin in 2015. The annual eco-compensation value of the river basin was closely related to local economic development and the implementation of eco-compensation

Table 9 Eco-compensation value of sub-industries in four counties (million ¥)

Time	County	Water consumption (10⁸ m³)	Eco-compensation value (million ¥)				Total eco-compensation value (million ¥)
			Agriculture	Industry	Life	Recreation	
2012	Xiping	0.160	1.16	0.80	0.35	0.02	2.34
	Shangcai	0.143	2.83	1.32	0.70	0.04	4.89
	Pingyu	0.170	1.04	0.47	0.30	0.01	1.82
	Xincai	0.209	1.10	0.55	0.20	0.02	1.85
2013	Xiping	0.126	0.90	1.06	0.27	0.06	2.28
	Shangcai	0.127	1.60	1.15	0.49	0.07	3.31
	Pingyu	0.123	0.88	0.66	0.45	0.04	2.03
	Xincai	0.162	0.87	0.79	0.23	0.04	1.92
2014	Xiping	0.277	2.49	2.42	1.13	0.39	6.44
	Shangcai	0.368	2.88	2.32	1.79	0.39	7.38
	Pingyu	0.335	1.86	1.70	1.19	0.27	5.02
	Xincai	0.406	1.83	2.07	0.91	0.30	5.12
2015	Xiping	0.203	1.14	1.34	0.39	0.22	3.09
	Shangcai	0.234	1.16	0.74	0.45	0.13	2.48
	Pingyu	0.218	1.00	0.69	0.37	0.12	2.17
	Xincai	0.281	1.22	0.84	0.43	0.14	2.64

Table 10 The affordability of water price of Xiaohong river basin in Zhumadian

Item	2012	2013	2014	2015
Per capita disposable income of residents (¥)	17671	19431	21320	22608
Per capita water expenditure (¥/m^3)	2.86	8.02	9.82	9.85
Annual per capita water consumption (m^3)	34.93	42.56	40.3	39.86
Per capita living water expenditure (¥)	99.90	341.33	395.75	392.6
Proportion of water expenditure (%)	0.56	1.8	1.9	1.7
Water price at 3% affordability (¥/m^3)	15.17	13.7	15.87	17.02
The value of water resources (¥/m^3)	18.37	19.35	19.15	17.01

mechanism. Economic development is not necessarily incompatible with ecological protection. Economic development should be based on the protection of environment and rational utilization of environmental resources (Hongliang et al. 2015). Perfect, continuous, and operable laws and regulations are a powerful guarantee for the implementation of eco-compensation, and the establishment of a system can effectively reduce pollution within the basin. The government should formulate an effective and specific river basin eco-compensation mechanism, create a legal environment for eco-compensation, and improve the management system.

In terms of regional space, the eco-compensation values of Xiping County and Shangcai County on the upper reaches were higher than those of Pingyu County and Xincai County on the lower reaches. This is due to the infrastructure projects initiated by Xiping County and the development of industry and agriculture in Shangcai County, where the rate of development of the secondary industry reached 11.1%. Along with economic development came increasing sewage discharge. The eco-compensation value of Shangcai County was the

highest among four counties, which was closely related to its economic development and pollution control capacity. It was difficult to adopt effective measures in Shangcai County to limit local sewage discharge, resulting in serious pollution of water bodies and the highest eco-compensation value. While sparing no efforts to develop the economy, it is necessary for the government in the regions on the upper reaches to strengthen the protection of water quality, strictly control sewage discharge, improve the quality and capacity of sewage treatment, and formulate an effective ecological protection policy to improve the water environment. Government departments at all levels should also establish an authoritative supervision and management system to supervise the administrative law enforcement and construction behavior of river basin ecological protection, and monitor the protection benefits and assess loss changes. Then, strong administrative measures can be taken to strengthen the ecological environment protection and construction in various counties.

From the perspective of sub-industries, industry and agriculture play essential roles in promoting the advancement of

Fig. 4 Trend map of eco-compensation value in sub-industries
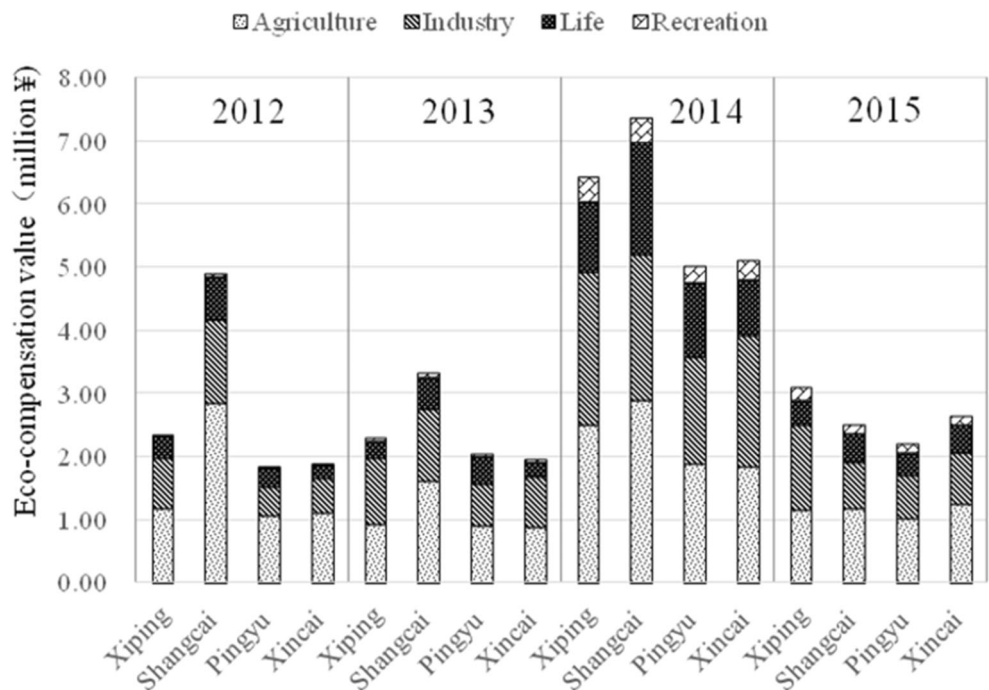
human society (Kun-Zhou 2017). The proportions of agriculture and industry development were always higher than those of life and recreation, so was the utilization of water resources. As a result, the eco-compensation values in agriculture and industry were always at a relatively high level, and the eco-compensation value of the recreation industry was the lowest among the four industries. On the one hand, it shows that the development of local tourism industry is relatively backward. On the other hand, it also indicates that the ecological protection policy has been effectively implemented in the local tourism industry. Through the analysis above, it can be concluded that it is crucial that agricultural and industrial bodies attach importance to ecological protection and the implementation of environmental policies, while the life and recreational industries should focus on economic development. While theoretical research is carried out, pilot work on eco-compensation in various industries in the basin should be conducted as soon as possible to find problems in practice and summarize experience constantly, to promote the establishment of eco-compensation mechanism and improve relevant policy.

From the perspective of feasibility of the results, the eco-compensation value is related to the economic development level, water resource endowment, and pollution control level of each county. Areas with higher per capita GDP mean that they have the ability to undertake greater reductions in pollutants, more responsibility for reducing emissions, and higher value of water resources, which has resulted in higher eco-compensation values. There are two kinds of results affected by the endowment conditions of water resources. One is that the small amount of water resources in the region leads to the high value of water resources, which improves the eco-compensation value of these regions. Second, the regional water resources are abundant, but the pollution is serious, leading to the high eco-compensation value. In areas with high levels of pollutant control, the discharged sewage can be discharged after good treatment, which greatly reduces the concentration of pollutants and increases the eco-compensation value. The calculation results of the ECQ-Is Model are consistent with the water resource status, economic development level, and pollution control level of each year, county, and industry, verifying the feasibility of the model to calculate the eco-compensation value of each industry in the basin. Moreover, this model can be used to divide the subject and object of compensation in upstream and downstream of the river basin in detail, clarify the compensation responsibilities of different industries, and effectively solve the problem of "the one that pollutes should compensate."

Analysis of capital flow of sub-industries in the river basin

According to Table 9, and combined with the mechanism analysis of the upstream and downstream eco-compensation in the river basin, the chart of the capital flow of eco-compensation value in sub-industries in the river basin is shown in Fig. 5. The year 2015 was taken as an example.
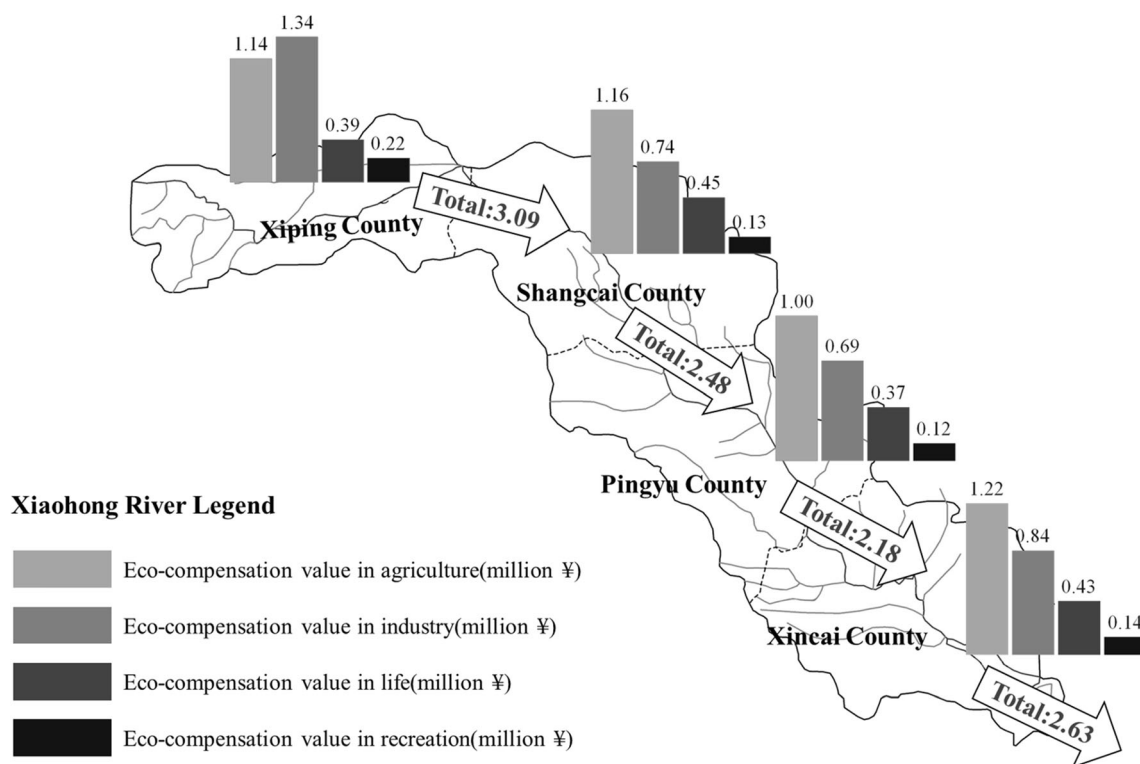

Fig. 5 The chart of the capital flow of eco-compensation value in sub-industries in the Xiaohong River Basin in 2015

Figure 5 shows the amounts of money (according to eco-compensation value) that sub-industries on the upper stream paid to their counterparts on the lower stream. For example, the industry of Xiping County compensated its counterpart of Shangcai County by 1.34 million ¥; the agriculture of Shangcai County compensated its counterpart of Pingyu County by 1.16 million ¥, and the four industries of Xincai County compensated the administrative region of on the lower reaches by 2.63 million ¥. According to the characteristics of the basin, the effects of human activities on the upper stream can be transmitted to the downstream region. The efforts of pollution control are inadequate in the upstream regions, due to better water quality and less pollution accumulation on the upper stream, plus the fact that it takes time to see the effects of pollution control. Driven by natural forces and the policies in social environment, the eco-compensation from upstream regions to downstream regions is still the general direction of ecological compensation. Due to the lack of environmental awareness, insufficient punishment, and weak supervision, the pollution control on the upper stream is far from active and sufficient, while the downstream regions effectively implement ecological protection policies, resulting in the fact that the pollution problem in upper reaches is more serious than that in lower reaches. Therefore, it is essential for the upstream region to strengthen people's environmental awareness in sub-industries, strictly control sewage discharge, increase the punishment for sewage discharge, and reasonably quantify the eco-compensation value of the river basin. The upstream industries should bear the responsibility for the loss of downstream industries caused by water pollution, which corresponds to the eco-compensation principle of "the one that pollutes should compensate."

From the perspective of the relationship between man and nature, the river basin is the spatial basis and an organic whole that witnesses the interaction between man and nature (Yoon et al. 2015). The upper stream and lower stream of the river basin are characterized by regional integrity, and the study of river basin eco-compensation is conducive to the coordination of the overall development of the river basin. In this paper, the ECQ-Is Model was only used to calculate the eco-compensation value from the upper stream to the lower stream in a river basin, while the ecological protection compensation value from the lower stream to upper stream was not calculated, and the regional integrity of the river basin was not taken into consideration. The two-way eco-compensation in the river basin can be a new research trend. Global research on eco-compensation is still in the preliminary stage of exploration, especially in terms of the eco-compensation of water quality in the river basin. There are many theoretical outcomes, but no uniform standard of calculation, so it is also necessary to explore simple and accurate research methods.

Conclusion

After consulting the studies on eco-compensation done by scholars at home and abroad, the author of this paper constructed the ECQ-Is Model. The case study is carried out in the Xiaohong River Basin of Zhumadian, and the eco-compensation values of four sub-industries—agriculture, industry, life, and recreation—in Xiping County, Shangcai County, Pingyu County, and Xincai County were calculated. The pollution loss rate and eco-compensation value of the downstream, industrial, and agricultural systems in the river basin were relatively high. Therefore, it is necessary to strengthen the protection of water quality. The research results can point out the direction for the management of ecological environment in the river basin.

The significance of this paper lies in the establishment of the ECQ-Is Model, which combines EMA and PLR to calculate the eco-compensation value of sub-industries. The calculation results prove that the model is feasible, practical, and universal. The clear division of responsibilities among the sub-industries in the upstream and downstream regions is beneficial to the progress of the work of eco-compensation. The establishment of this model provides new methods and new ideas for the study of eco-compensation in different industries in the basin, and it is also of great significance for determining the value of eco-compensation and the compensation way. However, it still needs some improvements. On the one hand, on the global scale, developed countries or regions can provide financial protection and technical support for ecological protection and reconstruction in less developed countries or regions. On the other hand, in this model, consideration is only given to the one-way eco-compensation of the water pollution loss in the upstream area to the downstream area. Subsequent research can continue to explore two-way eco-compensation for water environmental protection provided by the downstream region to the upstream region.

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