Ecological Indicators xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Ecological Indicators

journal homepage: www.elsevier.com/locate/ecolind

Study on the quantification method of water pollution ecological compensation standard based on emergy theory

Zening Wu, Xi Guo, Cuimei Lv*, Huiliang Wang, Danyang Di

School of Water Conservancy and Environment, Zhengzhou University, Zhengzhou, Henan, 450001, PR China

ARTICLE INFO

Keywords:
Water pollution
Ecological compensation
Emergy
Quantification

ABSTRACT

Water pollution compensation is one of the important economic means of water pollution control and management, and the quantification of compensation standard is the key link in the implementation of water pollution ecological compensation. Because the ecological compensation refers to ecological environment, society and economy at the same time, the emergy analysis method of ecological economics was introduced to the quantification study of water pollution ecological compensation standard to overcome the shortcomings of traditional methods, and the ecological economic value of pollutants dilution water is defined as water pollution ecological compensation standard In the process, the key pollutants in river was confirmed by water quality assessment, then the water dilution model was built and the dilution water amount when pollutant concentration meeting the standards of water quality section was determined on the basis of purification of key pollutants. Using the Qingyi River as an example, the water pollution compensation standard of the key pollutants (NH_3-N and COD) were calculated, which showed that the comprehensive compensation standard of NH_3-N are all higher than COD in six control section. Among them, the highest comprehensive compensation standard is 93.99 yuan/t in Heshang Bridge (Changge City), the next one is 74.07 yuan/t in Hutuo sluice, and Zengfumiao Village is without compensation. Therefore, the pollutant discharge levels are different in different section, and then their compensation standards are different. To sum up, the economic, social and ecological losses caused by water pollution were considered synthetically and the emergy method for the accurate quantification of water pollution ecological compensation standard was provided.

1. Introduction

The water pollution ecological compensation is an environmental economic policy and management system for controlling water environment pollution and promoting ecological protection by economic means. The accurate quantification of water pollution ecological compensation standard not only can benefit the rights security of different users, but also promote the effective implementation of various water pollution control measures.

In recent years, a series of research and exploration for water pollution ecological compensation were organized and developed by the Ministry of Science and Technology, the Ministry of Environmental Protection and other relevant departments (Yu and Xu, 2016; Guan, 2016; Ying, 2015; GuoHua and FengCun, 2008), which plays an important role in grasping the domestic and abroad research and practice of water pollution ecological compensation, clarifying its policy implications, establishing its theory, method and technology and setting up its typical model. For example, many quantification method of water pollution ecological compensation standard were made by relevant scholars, such as taking the recovery cost of water ecological as compensation basis (Liu Xiaohong, etc., 2007; Guangda, 2013), and based on water pollution economic loss evaluation (Shaoqing, 2012; Xuezhong et al., 2007), and estimating the ecological compensation standard model based on key water pollution factors (Taozhen and Shengbang, 2013). To sum up, the comprehensive analysis on research status shows that the quantitative method of water pollution ecological compensation standard is mainly economic method at present, which based on monetary theory, and all wealth are measured by monetary value. However, water pollution ecological compensation involves economic, social and ecological environment systems the economic and social compensation value can be calculated by conventional economic method, but the accounting for ecological environment compensation is difficult to achieve. As an objective substance, emergy flow can circulate through the natural ecological system and social economic system, which provides a unified and objective standard for the assessment of environmental resources and economy.

* Corresponding author.
E-mail addresses: zeningwu@zzu.edu.cn (Z. Wu), zzuguoxi@163.com (X. Guo), 366357398@qq.com (C. Lv), 28143242@qq.com (H. Wang), 695765150@qq.com (D. Di).

http://dx.doi.org/10.1016/j.ecolind.2017.09.052
Received 15 January 2017; Received in revised form 22 September 2017; Accepted 28 September 2017

Therefore, the quantitative calculation of water pollution ecological compensation was proposed by emergy theory and analytical method of ecological economics in this paper, and the water pollution compensation amount was expressed by ecological economic emergy value of pollutants dilution water. The economic, social and ecological losses caused by water pollution were considered synthetically and a new method for the accurate quantification of water pollution ecological compensation standard was provided.

2. Quantification method of water pollution ecological compensation standard based on emergy theory

Odum claimed that: "A science-based evaluation system is now available to represent both the environmental values and economic values with a common measure. Emergy is the energy memory or the total energy embodied in any product or service. It is defined as the sum of all the inputs of energy needed directly or indirectly to make any product or service (Odum, 1996; Shengfang, 2002). Emergy analysis is a quantitative research method for the process of ecological economic system, which can transform all kinds of material, different levels of energy and money into solar energy value by transformity (sej/J or sej/$), and the unified measurement of various material, energy is realized (Lv and Wu, 2009).

The overall thinking for quantification of water pollution ecological compensation standard based on emergy theory is taking the ecological economic emergy value of pollutant dilution water as the ecological compensation quantity of water pollution. The main steps are as follows:

2.1. Calculation of water resources ecological economic value

Emergy analysis is a quantitative research method for the process of ecological economic system, which can transform all kinds of material, different levels of energy and money into solar energy value by transformity (sej/J or sej/$), and the unified measurement of various material, energy is realized (Shengfang, 2002). Computation formula is as following:

$$EM = \tau \times B$$

Among which, EM is emergy, sej.τ is emergy transformity, sej/J or sej/g. B is energy or quality, J or g.

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 part: economic value, social value and ecological environment value (Lv, 2009; Wu, 2013). 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, then the ecological economic value of water resources can be obtained by vector addition.

$$EM_w = EM_c + EM_s + EM_e$$

In the formula, EM_w is the ecological economic value of water resources, sej/m^3; EM_c is the economic value, sej/m^3; EM_s is the social value, sej/m^3; EM_e is the ecological environment value, sej/m^3.

2.2. Determination of key pollutants

The water quality evaluation is processed according to the《Surface water environment quality standard》, and trend analysis is carried on. On this basis, the pollutants which exceed badly, volatile obviously and change apparently are chosen as the preliminary results of key pollutants. On this basis, the principal component analysis is carried out on the pollutants of monitoring section, through the role of each single index in comprehensive index of water quality, the key pollutants of river pollution is determined.

2.3. Accounting for water quantity of pollutants dilution

Suppose that the water pollution ecological compensation is to meet the needs of government administration, which takes overall sectional control, and water quality control uses the criteria of water functional area directly, without considering intermediate links and enterprises. According to the conservation of mass, the dilution water model which is needed when the water quality of key pollutants restore to the target water quality is established, then the quantity of water resources required for the restoration to water quality standards of the river restoration water function area is determined.

$$W_i = \frac{W_s(P_i - S_i - K_i \times P_i)}{S_i}$$

In the formula, W_i is the water quantity required for the restoration to water quality standards of the river restoration water function area of pollutant i, m^3; W_s is the sewage quantity to be diluted, m^3; P_i is the actual concentration of pollutant i, mg/L; S_i is the water quality standard of water function area, mg/L; K_i is the comprehensive attenuation coefficient of pollutant, which is a constant.

2.4. Establishing quantitative model of water pollution ecological compensation standard

Following the whole idea of quantization of water pollution compensation standard based on emergy theory, regarding the ecological economic value of pollutants dilution water as water pollution ecological compensation standard.

The calculation formula of the water pollution compensation standard as follows:

$$C = \frac{\max\limits_{i=1,2...n} W_i \times EM_W}{EDR \times W_s}$$

In the formula, C is the water pollution ecological compensation standard of per unit water, ¥/t; $\max\limits_{i=1,2...n} W_i$ is the largest dilution water quantity of different pollutant, m^3; EDR is the emergy currency ratio of basin, sej/¥.

3. Analysis of water pollution compensation case in Qingyi River (Xu Chang)

3.1. Study area

Qingyi River is the tributary of Ying River which belongs to Shaying River water system in the upstream of the Huai River Basin, originated in Goucaoyuan of Xinzheng City and gets into the territory of Xuchang at Guanting in Changge City. Qingyi River flows through Changge City, Yuzhou City, Xuchang County, Weidu District (Xuchang City), Yanling County and Linying City of Luohe City, imports Ying River at Taocheng sluice in Yanling County. The length of the Ying River is 149 km, and its catchment area is 2362 km^2, accounts for nearly 32.1% of the area of Ying River Basin. The total length of the river in Xuchang City is 79 km, the corresponding catchment area is 1585 km^2, accounts for 67.1% of the area of Qingyi River Basin. Qingyi River is one of the three major rivers in Xuchang City, whose tributaries include Shiliang River, Xiaohong River, Xiaoni River, Qingni River, Xueyuan River, Yingma River etc., the river's average annual inbound water volume is 0.27 million m^3.Qingyi River is important for flood control, drainage, sewage and urban landscape along the river area in Xuchang City. For a