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Original Research

Reduction of Point Source Pollutant Load: An Allocation Model for the Watershed TMDL Program

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Abstract

An allocation scheme of water pollutant reduction is the key procedure to implement a watershed total maximum daily load (TMDL) program. In order to improve the equity for the allocation scheme of water pollutant load reduction, five indexes involved in allocation processes were selected from fields associated with society, environment, economics, and resources. The weights of these indexes were determined by using fuzzy optimization and entropy weight methods, and a multi-dimensional Gini coefficient-based allocation model for watershed point source pollutant load reduction was established. Corresponding constraint conditions were set to optimize the allocation scheme of point source pollutant load reduction. This model embodies the variability in importance of various indexes in the allocation process, and improves the equity and scientific basis of the allocation scheme. It is a reasonably ideal allocation model, and was used to allocate amino nitrogen load reductions in the Zhangweinan River basin. As validated by the soil and water assessment tool (SWAT) model, the optimized reduction scheme meets the water quality criteria for the relevant water functional area in the watershed in various target years. Authors in this paper made great efforts for the reduction allocation of watershed point source pollutant load in the watershed with intensive anthropogenic activities. The results provide a scientific basis and technical support for water environmental protection and sustainable uses of water resources in the Zhangweinan River basin.

Keywords: point source load, Gini coefficient, allocation model, entropy weight method, Zhangweinan River

Introduction

River basin water pollution has always been of concern to researchers [1-5], and a scientific and reasonable formulation of allocation scheme for watershed water pollutant reduction is the key procedure to implement a watershed-scale total maximum daily load (TMDL) program. In this context, the pollutant load allocation is a contradictory entity – interest maximization and pollution minimization – involving water pollutant control technologies, economic feasibility, and load allocation equity; by virtue of its nature, it determines the rights of each pollutant discharger to utilize environmental resources and identifies the obligations of each pollutant discharger to reduce pollutants.

Eight kinds of relatively popular pollutant load analysis methods were compared and assessed in 1985 [6].

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The common allocation methods are often a combination of stochastic theory and system optimization [7], for instance Fujiwara et al. [8] employed a probabilistic constrained model to allocate the total load of water pollutant discharge among sewage outfalls, while other researchers utilized and optimized the probabilistic constrained model to accomplish pollutant allocation among sewage outfalls [9, 10]. Other methods such as the linear programming method [11, 12] and the direct inference method [13] also have been applied. Moreover, some researchers have studied multipoint source pollutant load allocation methods [11, 14, 15] and pollutant load allocation between a point source and a nonpoint source [16]. The U.S. Environmental Protection Agency (USEPA) has provided 19 pollutant load allocation methods for implementing a TMDL program.

In China, based on water environment capacity or targeted total load control in accordance with the principles of economic optimization and equity and reasonability [17], pollutant load allocation has been carried out. In recent years, watershed pollutant reduction allocation gradually became a hot topic in China. Take the degree of satisfaction and fairness deviation as a measure, based on the best coordinated solution to maximize the minimum strike, Lin Gaosong et al. [18] conducted equitable distribution of emissions in Guangzhou – Foshan cross-border river region. By learning the basic concepts of the Gini coefficient, Wu Yingyue et al. [19] constructed an approach to assess the reasonability of the total water pollutant distribution plan between the basin.

As the Gini coefficient is a measure of the degree of distribution justice, so the Gini coefficient in economics concepts and methods is introduced into the watershed pollutant load reduction distribution. Gini coefficient methods are often used in water pollutant discharge load reduction allocation for watershed total load control in China [20-25]. The common Gini coefficient-based allocation methods are grouped into two main types, one in which the allocation scheme is adjusted by reducing a single index [20], while the other includes many more Gini coefficient-based allocation methods, which use the sum of single-index Gini coefficients for the minimum as the object function [22, 25-29] or establish a multidimensional water environment Gini coefficient with weight coefficients being assigned values subjectively [30]. Li Ruzhong and Shu Kun [31] established a comprehensive Gini coefficient, determining the weight of each single evaluation index by means of a fuzzy optimization method and an entropy weight method, and set the elastic constraint conditions for the object function that the comprehensive Gini coefficient is the minimum to optimize the allocation scheme; and applied the comprehensive Gini coefficient method in the total load allocation of the chemical oxygen demand (COD) and amino nitrogen in the Chao Lake watershed. Some disadvantages exist for all of these allocation methods, e.g., the chosen single socioeconomic indexes fail to reflect adequately the social, economic, and resource states of each region, constraint conditions are set too strictly, and the difference in importance of various single indexes cannot be reflected. To address the issue of amino nitrogen load allocation in the Zhangweinan River Basin watershed under intense anthropogenic impact, this paper optimally selected relevant indexes, normalized related data, introduced a weight coefficient, and established a multidimensional water environment Gini coefficient-based allocation model to optimize and solve for the allocation scheme with various constraint conditions being set and to analyze the allocation scheme feasibility. The results will provide a scientific basis and technical support for water environmental protection and sustainable use of water resources in the Zhangweinan River Basin. Meanwhile, the findings will become a very important reference for point source pollution control and watershed ecological restoration faced by developing countries.

Methodology Description

Establishing the Multidimensional Water Environment Gini Coefficient-Based Allocation Model

(1) Determine the discharge and standard discharge of pollutants among regions to be allocated within the watershed while collecting the regional socioeconomic index.

(2) Normalize raw data using the following calculation formula:

$$E_{mj} = \frac{w_{mj} - w_{\min j}}{w_{\max j} - w_{\min j}} \tag{1}$$

...where E_{mj} is the normalized value of the jth index in the mth region, W_{mj} is the initial value of the jth index in the mth region, $W_{\max j}$ is the maximum value of the jth index within the watershed, and $W_{\min j}$ is the minimum value of the jth index within the watershed.

(3) Introduce a weight coefficient to plot a water environment Lorenz curve of multiple indexes versus the pollutant discharge load based on the normalization result of each single index, and calculate the multidimensional water environment Gini coefficient. The determination of index weights will be detailed in the next paragraph. The expression of the multidimensional water environment Gini coefficient is as follows:

$$G_m = \sum_{j=1}^{n} E_{mj}\omega_j \tag{2}$$

...where

$$\sum_{j=1}^{n} \omega_{mj} = 1 \tag{3}$$

...where G_m is the multidimensional water environment Gini coefficient of the mth region, E_{mj} is the normalized value of the jth index in the mth region, and ω_{mj} is the weight of the jth control index in the mth region, in which $0 \le \omega_{mj} \le 1$. When $\omega = 0$, it means that the jth control index is disregarded; when $\omega_{mj} = 1$, it means that only the jth control index is taken into account, i.e., the single-index water environment Gini coefficient of the jth control index.

(4) Calculate the established multidimensional water environment Gini coefficient:

$$G_j = 1 - \sum_{i=1}^{n} (x_{j(i)} - x_{j(i-1)})(y_{j(i)} + y_{j(i-1)}) \quad (4)$$

...where G_j is the water environment Gini coefficient for index j, $x_{j(i)}$ is the cumulative percentage of the single index j, $y_{j(i)}$ is the cumulative percentage of the pollutant based on the single index j, and n is the number of allocated administrative regions. When $i = 1$, $x_{j(i-1)}$, $y_{j(i-1)}$ is (0, 0).

(5) Take the multidimensional water environment Gini coefficient for the minimum as the object function, and optimize the allocation scheme under relevant constraint conditions. The object function is:

$$\min = G_m$$

The constraint conditions are as follows: the total load reduction constraint is:

$$\sum_{i=1}^{n} W_i \leq W_0$$

The *status quo* Gini coefficient constraint of each index is:

$$G_j \leq G_{0(j)}$$

The reduction ratio constraint of each region is:

$$p_{i0} \leq p_i \leq p_{i1}$$

And the ranking constraint of each region is:

$$K_{j(i-1)} \leq K_{ji} \leq K_{j(i+1)}$$

Determining the Weights

Assuming that there is in total n administrative regions within the watershed, that each administrative region has a load reduction allocation index system composed of m indexes, and that every index of each administrative region has a specific value, called the eigenvalue [32], the corresponding eigenvalue matrix for the set of m indexes in n administrative regions is

$$\begin{bmatrix} E_{11} & \cdots & E_{1n} \\ \vdots & \ddots & \vdots \\ E_{m1} & \cdots & E_{mn} \end{bmatrix} = (E_{ij})_{m \times n} \quad (5)$$

...where $n = 27$ and $m = 5$ in this paper.

Many social, economic, and environmental factors are involved in the m indexes that affect the watershed total water pollutant load reduction allocation. We used a fuzzy optimization method to normalize the index eigenvalues of each region, calculated the relative subordinate degree of each index, and employed an entropy weight method to calculate the weight of a single index [31, 32].

Calculating the Relative Subordinate Degree of Each Index

(1) Calculate the relative subordinate degree of the greater-the-better index:

$$r_{ij} = \frac{E_{ij}}{\max\limits_{j=1,\ldots,n}\{E_{ij}\} + \min\limits_{j=1,\ldots,n}\{E_{ij}\}} \quad (6)$$

(2) Calculate the relative subordinate degree of the smaller-the-better index:

$$r_{ij} = 1 - \frac{E_{ij}}{\max\limits_{j=1,\ldots,n}\{E_{ij}\} + \min\limits_{j=1,\ldots,n}\{E_{ij}\}} \quad (7)$$

Determining the Relative Subordinate Degrees of the Matrix of Indexes

After the relative subordinate degree of each single index was calculated, the relative subordinate degree matrix for various single index eigenvalues was obtained [32]:

$$R = (r_{ij})_{5\times 27} \quad (8)$$

Calculating the Index Weight

We introduced information entropy into the index weight determination, and used information entropy to calculate the weight of each single index [31]. In information theory, the information entropy is defined as

$$H(r) = -\sum_{i=1}^{5} r_{ij} \ln r_{ij} \quad (9)$$

The larger the variation in a single index value, the smaller its information entropy, the more the information quantity this index provides, and the higher its weight. Conversely, the smaller the variation in a single index value, the greater its information entropy, the less the information quantity this index provides, and the lower its weight. Consequently, based on the variation of each single index, we can use information entropy to determine the weight of each single index in a procedure as follows:

- Step 1 – calculate the entropy e_i of the ith index:

$$e_i = -k \sum_{j=1}^{n} r_{ij} \ln r_{ij} \quad (10)$$

- Step 2 – calculate the variation coefficient of the *i*th index:

$$h_i = 1 - e_i \quad (11)$$

- Step 3 – normalize the variation coefficient and determine the weight of each index:

$$\omega_i = h_i / \sum\nolimits_{i=1}^{5} h_i \quad (12)$$

...where $k = \ln n^{-1} > 0$, $e_i > 0$

Based on the weight of a single index, we plotted the multidimensional water environment Lorenz curve and calculated the multidimensional water environment Gini coefficient. We optimized the multidimensional water environment Gini coefficient with its value a minimum as the objective under relevant constraint conditions to obtain the optimal solution and complete total load reduction allocation.

Application of the Allocation Model Result Analysis

Establishing the Model

The allocation model established above was used to allocate the amino nitrogen pollutant reduction load of the Zhangweinan River Basin among administrative regions. It was determined that the Zhangweinan River Basin has a total of 101 major sewage outfalls distributed in 35 subbasins over 27 administrative districts and counties in the watershed. In 2004 the *status quo* discharge load of watershed point source amino nitrogen was 45,979.06 kg/day, of which the standard discharge load was 19,506.84 kg/day and the amino nitrogen environment capacity of the watershed was 3,778.31 kg/day. Since the amino nitrogen concentrations at numerous outfalls failed to meet the respective discharge criteria, and the standard discharge from outfalls is the basis of the total load reduction, the polluters' duly obligation and liability, and a prerequisite for formulating and implementing the watershed point source pollutant reduction plan, but the data on the standard discharge load are easily available and the standard discharge is usable, reflects the principle of respecting the history and acknowledging the *status quo*, and facilitates the actual implementation of the final allocation scheme, this study selected the standard discharge load of each county (city or district) as the initial value for the watershed total amino nitrogen load reduction allocation.

In the Gini coefficient-based allocation model, the choice of indexes has a direct impact on the equity and reasonableness of the allocation result, so the indexes will largely reflect those factors that affect the water pollutant discharge load reduction allocation, and their data will be easily available and comparable, typically including population, economic, and resource factors and the water environment carrying capacity. In this study, the social factor was characterized by population quantity; the economic factor was characterized by two indexes, the regional gross domestic product (GDP) per capita and the gross industrial output value of enterprises above a designated size; the natural factor was characterized by the land area of administrative region; and the resource factor and the water environment carrying capacity were characterized by the regional water environment capacity. The Gini coefficient of the population versus the water pollutant discharge load reflects the variation in the water pollutant discharge per capita; where the pollutant discharge load per capita is high, the reduction magnitude should be raised. The Gini coefficient of GDP versus the water pollutant discharge load reflects the variation in the water pollutant discharge load per unit GDP; if this Gini coefficient is large, it implies that economic development is not consistent with environmental protection in this region, with people and water poorly harmonized, so the reduction ratio should be increased to promote industrial restructuring and trade-off between economic growth and environmental protection. The Gini coefficient of the water environment capacity versus the water pollutant discharge load reflects the variation in the water environment quality: the larger the Gini coefficient, the worse the water environment quality, and the more the pollutant reduction. The Gini coefficient of the gross industrial output value of enterprises above 10,000 RMB yuan versus the water pollutant discharge load reflects the water pollutant discharge load in the industrial field, and indicates the variation in the pollutant discharge per unit industrial output value from the perspective of the economic contribution [32].

The above five indexes involve social, economic, resource, and environmental fields, largely reflecting various factors that affect the water pollutant load allocation. Their data are relatively easily available, and they constitute the index system for calculating the Gini coefficient. Amino nitrogen was chosen as the water quality factor, or the state variable: the aforementioned five indexes served as independent variables, and various administrative regions (counties) acted as the subjects of the total load allocation, and the state variable and independent variables were then normalized before plotting the water environment Lorenz curve for each single index and calculating the Gini coefficient [32].

The weight coefficients of these five indexes were determined using the weight computing method: 0.2345 for the administrative region area, 0.2272 for the population, 0.2198 for GDP, 0.2025 for the gross industrial output value of enterprises above 10,000 RMB yuan, and 0.1159 for the amino nitrogen environment capacity. A multidimensional water environment Gini coefficient-based allocation model was then established, and a multidimensional water environment Gini coefficient Lorenz curve was plotted.

Selecting Alarm Values

In the process of allocating the total load of watershed water pollutant reduction, the equity of the valuing interval needs to be reconsidered [28]. As index variation exists among regions in the watershed (administrative region area, population, GDP, pollutant water environment capacity, etc.), some indexes have high water environment Gini coefficients (e.g., the *status quo* discharge and standard discharge of the water environment Gini coefficient over the administrative district area in this study are 0.694 and 0.726, respectively). So, it is impossible to employ the valuing interval commonly used in economics to measure the equity of the total load allocation scheme. In terms of the water environment Gini coefficient, an equity criterion must take into account the actual water environment capacity and the *status quo* of resource exploitation and utilization. Therefore, there is no strict limit at which the water Gini coefficient level is equitable. Ye Chunyan [22] defined the reasonable range of the Gini coefficient as 0-0.3 when allocating the total load of water pollutant in Deyang City. Zhang Lifeng [21] regarded 0.2-0.4 to be a reasonable range for the Gini coefficient, with 0.4 being the alarm value; if 0.4 is exceeded, then the Gini coefficient should be adjusted so that the total load allocation tends to be balanced. This viewpoint is applied widely in China [23, 24, 31, 33]. When studying the total water pollutant load allocation of the Changle River watershed, Chen Dingjiang [30] considered making the Gini coefficient the minimum under the corresponding compression condition to be an equitable and reasonable criterion, which agrees with the viewpoint of Dong Zhanfeng [20] that it is unrealistic to adjust the Gini coefficient to below 0.4, and what should be done is simply to solve for a relatively optimal solution under a series of constraint conditions. This study takes the optimal solution of the Gini coefficient in a multidimensional water environment under constraint conditions as the equitable and reasonable criterion, when the Gini coefficient is a minimum, which is in agreement with the aforementioned notions.

Setting Constraint Conditions

When optimizing the multidimensional water environment Gini coefficient, constraint conditions need to be set. This study requires adjustment of the reduction ratio, provided that the water environment Gini coefficient for each single index is not raised as high as possible. In other words, let the multidimensional water environment Gini coefficient be its minimum while ensuring that the equity of allocating each single index does not become worse, as far as is possible. Meng Xiangming [27] held that doing so can prevent the final allocation scheme from deviating from equity because of a reduction in equity of a single index, guaranteeing the true equity of the allocation scheme to the maximum extent.

It is necessary to ensure that the rank of the single index pollutant discharge load is kept consistent with the *status quo* values, so as to upgrade implementability of the final allocation scheme. According to Meng Xiangming [27] and Dong Zhanfeng [20]: in the Lorenz curve with respect to a single socioeconomic index of the water environment, the order of administrative regions is fixed, and ranks of different indexes differ greatly due to development imbalance among regions; the rank of a single index is very important, and should the rank change during adjustment, then a qualitative change takes place in the corresponding index of the administrative region. However, in fact, it is often very difficult for the rank to change in a limited time; in other words, if the rank is not restricted to be constant, then the allocation scheme eventually determined will be impossible to implement later. Therefore, we set the rank of a single index to be constant during adjustment as a constraint condition for optimizing the multidimensional water environment Gini coefficient.

Discussions

Considering that the study area is a watershed subject to intense anthropogenic interference, all of its *status quo* Gini coefficients are greater than 0.4 and, in light of the water quality state, the water functional area, the water quality control target, and the environment capacity, we can allow the standard discharge area to engage in a small reduction task, or none. To ensure that the total load of amino nitrogen discharge is less than or equal to the environment capacity after the watershed pollutant reduction, and that the water quality meets the requirement of the corresponding water functional area, two constraint conditions were set for optimization: one was that every single index is less than or equal to its *status quo* value, the other allowed a particular index to increase slightly, provided that the multidimensional Gini coefficient can be reduced. Both scenarios must satisfy other constraint conditions. These two scenarios correspond to reduction scheme 1 and reduction scheme 2, respectively (Fig. 1). The multidimensional water environment Gini coefficient allocation model was optimized according to constraint conditions, and the optimized comprehensive index Gini coefficient and the single-index Gini coefficients and their variations are shown in Table 1.

As seen in Table 1, the Gini coefficients of the five indexes versus the amino nitrogen *status quo* discharge in the Zhangweinan River Basin and of the multidimensional water environment *status quo* value range from 0.594 to 0.694, far more than 0.4. Gini coefficients of all single indexes, and the general index exceeds 0.6, exhibiting a dramatic difference from the alarm value in economics, and the Gini coefficient of the other index is also close to 0.6. This indicates that, in terms of the area of the administrative region, the population of the administrative region, GDP, the gross industrial output value of enterprises above a designated size, the environment capacity, and the comprehensive multidimensional water environment Gini coefficient, the *status quo* discharge of amino nitrogen in the Zhangweinan River Basin is severely unbalanced. When all point source sewage outfalls have a standard discharge, the Gini coefficients of four single indexes and the comprehensive index become smaller than for the *status quo* discharge, indicating that, at the time of the standard discharge, the Gini coefficient of the population versus the amino nitrogen water environment, the Gini coefficient of GDP versus the amino nitrogen water environment, the Gini coefficient of the gross industrial output value of enterprises above a designated size versus the amino nitrogen water environment, the Gini coefficient of the environment capacity versus the amino nitrogen water environment, and

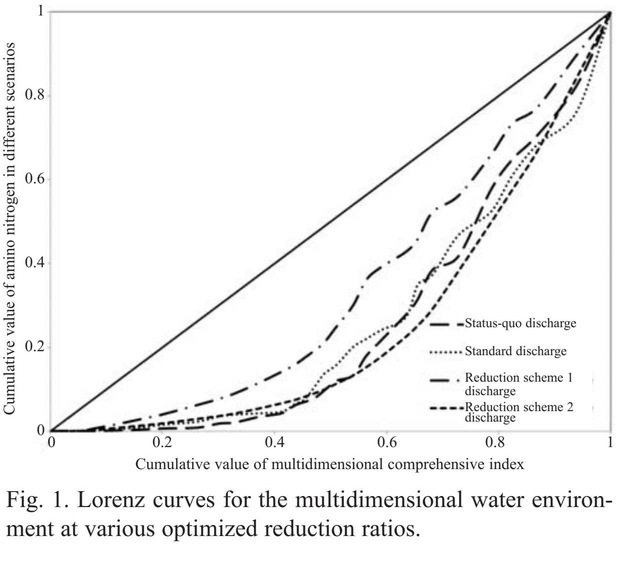

Fig. 1. Lorenz curves for the multidimensional water environment at various optimized reduction ratios.

Table 1. Water environment Gini coefficients of a single control index versus the amino nitrogen discharge load.

Reduction scheme	Allocation control index	Area of the administrative region	Population	GDP	Gross industrial output value of enterprises above a designated size	Environment capacity of amino nitrogen	Comprehensive index
Status quo discharge and standard discharge	Water environment Gini coefficient of *status quo* discharge	0.694	0.665	0.615	0.594	0.682	0.609
	Water environment Gini coefficient of standard discharge	0.726	0.544	0.501	0.469	0.528	0.520
	Reduction	-0.032	0.121	0.114	0.125	0.154	0.089
	Reduction magnitude	-4.6%	18.2%	18.5%	21.0%	22.6%	14.6%
Reduction scheme 1	Optimized water environment Gini coefficient	0.611	0.396	0.399	0.340	0.407	0.338
	Reduction	0.083	0.269	0.216	0.254	0.275	0.271
	Reduction magnitude	12.0%	40.5%	35.1%	42.8%	40.3%	44.5%
Reduction scheme 2	Optimized water environment Gini coefficient	0.736	0.519	0.541	0.508	0.272	0.501
	Reduction	0.042	0.146	0.074	0.086	0.410	0.108
	Reduction magnitude	-6.1%	22.0%	12.0%	14.5%	60.1%	17.7%

All reduction magnitudes are calculated on the basis of the *status quo* discharge.

the Gini coefficient of the comprehensive multidimensional water environment tend to be more balanced. However, the Gini coefficient of the administrative region area versus the amino nitrogen water environment rises, which is probably related to the fact that the established allocation model has as its objective the multidimensional water environment Gini coefficient as the minimum and globally optimal [31]. For allocation models based on the baseline year, objective and inherent unfairness exists in the industrial structure, the economic development demand, and the water resource supply, and these factors must be embodied in the final allocation scheme. If people simply pursue equity regardless of actual differences between regions and overrate the reducing Gini coefficient of a single index, this might aggravate the imbalance in regional socioeconomic development and further degrade the water ecological environment. In addition, Xiao Weihua et al. [24] consider that reducing the total load will also limit the reduction magnitude of the Gini coefficient. A reduction of watershed pollution is carried out on the pretext of respecting the history of and acknowledging the *status quo*, while all sewage outfalls are required to have a standard discharge to guarantee that the subsequent allocation scheme is executable; therefore, a slight rise in the Gini coefficient of a particular index during pollutant reduction is an expected phenomenon.

For two schemes in this study, different constraint conditions were set and their Gini coefficient reduction magnitudes were different, too. An appropriate reduction objective and suitable constraint conditions will be formulated on the basis of an adequate survey of the actual pollution discharge and the water environment capacity in a watershed. Formulating and implementing a watershed point source pollutant reduction plan is a long-term system objective, and it is impossible to reach the reduction target in a single stage by decreasing the Gini coefficient, because this does not comply with the basic philosophy of TMDL. The equity of a pollutant load reduction allocation scheme has to be adjusted and optimized step by step. Should the equitable Gini coefficient valuing range commonly used in economics be directly adopted to measure the reasonability of an allocation scheme, this study would fail to decrease the Gini coefficient to an absolutely or relatively equitable interval in one step. As for the two different reduction schemes in this study, the Gini coefficients of all single indexes and the comprehensive index in scheme 1 were smaller than those in the case of standard discharge, indicating that allocation scheme 1 tends to be equitable in many aspects, and it is the most ideal reduction allocation scheme. In reduction scheme 2, the Gini coefficients of a notable number of indexes did not fall below the alarm value (0.4) of traditional economics, hence this scheme can be executed as a priority as the immediate reduction scheme, in light of the practical situation and the economic development demand.

Calculation of the regional amino nitrogen reduction and the reduction ratio shows that those regions with a higher *status quo* discharge engage in heavier reduction tasks. This indicates that the established allocation model is equitable as a whole, and the allocation results comply with the practical watershed situation to facilitate allocation scheme implementation, so it is a feasible allocation scheme. The multidimensional water environment Gini coefficient-based allocation model was established on the basis of fuzzy optimization and an entropy weight method, taking into account the regional population, the area of the administrative region, GDP, the industrial development level, and the regional water environment capacity, while respecting the history and *status quo*, so it guarantees an equitable and reasonable allocation of the total load reduction to the maximum extent, and assures the smooth implementation of the allocation scheme.

After amino nitrogen reductions are allocated among administrative regions in the watershed, the reduction task assigned to each administrative region has to be further allocated to sewage outfalls. Pollutant reductions are allocated among sewage outfalls in an administrative region by means of an equal-ratio reduction method. The equal-ratio reduction method is an allocation method for pollutant reduction, with the ratio of the *status quo* discharge of each sewage outfall over the total discharge load of the region as the weight; this allocation method is advantageous in low data demand and simple processes, but it does not take into account the difference in pollutant discharge among industries and historical levels of treatment of various pollution sources. Such inequity is effectively avoided in this study because the first allocation result has been allocated among sewage outfalls based on standard discharge.

Conclusions

(1) To address the issue of watershed point source pollutant load reduction subject to intense anthropogenic interference, and to improve the equity and implementability of the water pollutant load reduction allocation scheme, we selected five indexes, namely population, GDP, water environment capacity, industrial output value, and the area of the administrative region, from social, environmental, economic, and resource fields involved in the allocation process, established an equitable multidimensional water pollutant load allocation model based on the Gini coefficient, and optimized the model to obtain an allocation scheme. The application of this allocation scheme to the amino nitrogen load allocation in the Zhangweinan River Basin justifies its equity and reasonability.

(2) A fuzzy optimization method and information entropy weight were introduced to determine the weight of a single index for the multidimensional water pollution allocation model, which embodies variability in the importance of various indexes in the allocation process. The final pollutant load reduction allocation scheme was obtained through optimizing the established multidimensional Gini coefficient, so the equity and scientific basis of the allocation scheme were improved.

(3) The case study of amino nitrogen load reduction in the Zhangweinan River Basin by setting different constraint conditions indicates that the established multidimensional Gini coefficient-based allocation model efficiently overcomes the flaws in existing water pollutant load allocation methods based on a single Gini coefficient and an equal-weight multidimensional Gini coefficient, so it is a reasonably ideal allocation model.

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