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The Quantitative Analysis of Ecological Compensation Responsibility in Watershed

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Abstract

This paper firstly propose to solve the responsibility definition problem in the calculation of eco-compensation quantity. It adopts Gini coefficient method to allocate emission permit according to the principle of equity and efficiency. And establish nine indicators mainly equity indicators to allocate the water rights. The paper firstly tries to allocate water rights in the Huaihe watershed in China.

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Key words: Watershed; Ecological Compensation Responsibility; Quantitative Analysis;

1. Research background and significance

With the rapid economic development、fast population growth and urbanization progress. More and more serious environmental problems emerged in the rivers of our country. One monitoring report of 1300 rivers in 2004 shows that class IV water quality、class V water quality and water quality less than class V account for 40% of total length of those rivers[1]. Therefore, Addressing river pollution problem nowadays is an very urgent task. As most of the rivers cut across different districts, water pollution in our country is characterized by trans-district or transboundary pollution.

Multi-year average volume of water resource of Yangtze watershed is 996 billion m3， water resource in this watershed is very plentiful. However, spatial and temporal distribution of the water volume of Yangtze watershed is very unbalanced. In the dry year or dry season, several tributary regions experience water shortage problem; In the entrance of Yangtze river, there is saline water intrusion at recent years

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resulting from decreased water from upstream. For the past few years, there are already several serious water resource conflicts, for example, Tongming river water conflict happened in the boundary of Sichuan and Guizhou province. These facts reflect that in the watershed rich in water resource like Yangtze watershed, water resource conflicts emerged due to uncertain water rights[2]. Practices has proved that water management pattern which use district as management unit can not be tailored to recent water environment and resource problems, we must find solutions from the perspective of the whole watershed scale.

It is very complicate to define environmental responsibility among each district of watershed, since attaining reasonable definition has to take account of fairness, efficiency, as well as legal rule and historical factors. Zhao et al. [7] has demonstrated that the mechanism of macroscopical regulation by means of emission trading (MMRET) is significantly preferable to the mechanism of appointed quota of pollution reduction in China. In the frame of MMRET, the definition of environmental responsibility can be actually transformed into the initial allocation of pollution permits among districts in the watershed. Therefore, the problem left to us is how to allocate the pollution permits efficiently and fairly. This paper involves two phases to define the environmental responsibility of each district in the watershed. The first phase is to determine the optimal allocation strategy of emission permits for districts in the watershed by establishing an emission permits allocation model. Then, we employ the formulation of emission permits and water quality to define the final environmental responsibility of each district. To model the allocation of emission permits, we develop a non-linear programming model seeking for least abatement cost based on the reasonable fairness among the individual district, by which the initial emission permits of each district could be calculated.

2. Allocation of initial emission permits

In the study, we assume that watershed covers N districts; in addition, each district can take measures to restrain their pollutants to their own area or transfer the pollutants to downstream. They can decide the amount of pollutants remained in their own area or transferred to downstream as well. The main variables and symbols are as follows:

ACi (i=1, 2, 3, … N) is the industry emission abatement cost function of district i, it can be estimated using econometric model: $AC = \xi W^{\alpha} \eta^{\beta}$, $\eta = (I - E)/S$ [8], where W represents annual discharge of sewage, I, E represents the average pollutants concentration of inlet and outlet of pollution treatment equipment respectively. S is the type III discharge standard of pollutants concentration.

Pi (i=1, 2, 3, … N) is the initial emission permits allocated to district i.

Pimax is the river water environmental capacity of the watershed attched to district i.

P0i’ is the present emission of district i

$\bar{P}_i$ is the mean historical emission of district i

ei is the “equity emission index” of district i

The standard formulation of the policy-maker’s optimization problem is to minimize the emission abatement cost, defined here as:

$$Min\pi = \sum_{i=1}^{i=N} AC_i \tag{1}$$

Subjects to two restraints: the aggregate emission restraint and “equity restraint”.

In this paper, the initial allocation of emission permits is carried out in the overall watershed. Considering the fairness of each district, upstream do not necessarily enjoy all the river water environmental capacity of watershed attached to their geographical areas, in other case, they can even occupy downstream's water environmental capacity, which means downstream must reduce their emission in order to compensate the increment of pollution that upstream bring on.

（1）Aggregate emission restraint: the total emission permits allocated are equal to the overall water environmental capacity of watershed.

$$\sum_{i=1}^{i=N} P_i = \sum_{i=1}^{i=N} P_{i\max} \quad (2)$$

（2）"Equity restraint": According to the conception of Gini coefficient which is an index to estimate equity of income, a specific method is established to evaluate the scenario of allocation of water emission permits among districts in the watershed. Correlative factors of the Gini coefficient for emission permits allocation are population, future development planning, and level of pollution control and mean historical emission. Among them, population-initial emission permits Gini coefficient accounts for the difference of the permits allocation per capita among each district. Kvemdokk[9] regards the allocation of emission permits in terms of population as politically and ethically acceptable. Thus, it may be unfair that more pollution permits are allocated to the region with smaller population.

In addition, we verge future development planning factor and level of pollution control factor into "equity emission index"-initial emission permits Gini coefficient, which reflect that watershed regulator should take into account the synthesized impact of economic development level, level of pollution control, level of production and technology, and future development planning. The result of allocation should not limit the development of backward areas, and provide incentive for conducting cleaner production technology or the transform of traditional high-contamination industrial structure. "Equity emission index" can be described as:

$$e_i = \frac{(1+a_i)^k / (1+\overline{a})^k}{(P_{0i} / GDP_i) / \overline{(P_0 / GDP)}}$$

Where a_i represents the expected economic growth rate of district i in the future development planning, a_i is the average expected economic growth rate of all the districts in the watershed, k is the duration of the planning. P_{0i} / GDP_i indicates the emission per *GDP* of district *i*, $\overline{(P_0 / GDP)}$ is the average emission per GDP of all the districts. In the case that the pollution units of a district adopt cleaner technology or transform into the industry with light pollution, and the expected economic growth rate of this district is high, hence, the district will be granted more discharge permits.

Considering that most of upstream areas are undeveloped region, their capability of technical innovation is restricted, therefore the allocated emission permits will be relatively few according to the allocation indicator of level of pollution control, this will results in "the Matthew effect". In order to reduce the influence of this effect bring to the principle of fairness, considering the discrepancy of different regions, we employ "compensation ability" indicator which can be expressed by GDP per capita. The weaker the "compensation ability" is, the more emission permits are allocated.

In order to guarantee the equity in the time scale, the initial allocation of emission permits needs to be stable among years, which denotes that there should be no significant difference between initial emission permits and mean historical emission, therefore, mean historical emission- initial emission permits Gini coefficient is developed to measure this equity. We introduce P_i to describe the mean historical emission. For reasons that the closer the year is, the more demand information of emission included in the historical emission, we employ exponential smoothing method to estimate P_i :

$$\overline{P_i} = \alpha P_i^{T-1} + \alpha(1-\alpha)P_i^{T-2} + \alpha(1-\alpha)^2 P_i^{T-3} + \cdots. \quad i = 1, 2, 3, \ldots, N$$

Where T represents the year for initial allocation, P_i^{T-1} describe the emission of year T-1 and so on, α (0< α <1) is a weighted coefficient, which specifies the reliance of initial emission permits on the demand information of emission in the year T-1. The larger value of α will lead to the shorter data sequence.

The smaller above Gini coefficients are, the fairer initial allocation is. In the evaluation of the allocation of income, due to the limitation of social development, it is impossible to distribute income perfectly equal, so there is little possibility that Gini coefficient is less than 0.2. The reasonable range of Gini coefficient should be 0.2-0.4. However, in the sphere of environmental problem, if there is no conflict of natural resource among regions, the Gini coefficienct could approximate to 0, Wu Y Y et al.[10] define the reasonable scope of Gini efficient as 0-0.2 in evaluation of the total pollutant load allocation among seven river basins of China. On the other hand, If there are frequently transboundary pollution events among regions, and there is no well-established coordination mechanism for environmental conflict, Gini coefficient may be magnified. In the study of the equity evaluation of total load allocation for atmosphere pollutants, Liu Y et al.[11] specified 0-0.3 as the reasonable scope of Gini coefficient. In our study, based on the fact that coordination mechanism for environmental conflict among districts of watershed is not yet mature, and the problem of transboundary pollution is overwhelming, we define the reasonable scope of Gini coefficient as 0-0.3.

According to the calculation of the cumulative percentages of initial emission permits, "equity emission index", mean historical emission and population, we further adopt trapezoid planimetry to compute the Gini coefficients based on the factors of population, "equity emission index" and mean historical emission respectively. These are described in following manner:

$$G_j = 1 - \sum_{i=1}^{N} (X_{j(i)} - X_{j(i-1)})(Y_i + Y_{i-1})$$

$$X_{j(i)} = X_{j(i-1)} + M_{j(i)} / \sum_{i=1}^{N} M_{j(i)}$$

$$Y_i = Y_{i-1} + P_i / \sum_{i=1}^{N} P_i$$

Where $X_{j(i)}$ is the cumulative percent of factor j; $M_{j(i)}$ is the value of factor j in district i; Y_i is the cumulative percent of initial emission permits; P_i specifies the initial emission permits of district i; when $i=1$, ($X_{j(i-1)}$, Y_{i-1}) is treated as (*0,0*). Because all the Gini coefficients range from *0* to *0.3*, the constraint conditions are:

$$G_j < 0.3 \tag{3}$$

3. Environmental responsibility definition

Subjecting to (2), (3), with the objective of (1), a non-linear programming model is described in last chapter, we solve the allocation of initial emission permits using software Matlab.

The optimum solution of this non-linear programming model, P_i^* , is the optimal initial emisssion permits allocated to each district of watershed. Incorporating the principle of efficiency and fairness, this allocation strategy should be the accepted method by all the districts of watershed. Water quality of cross-section (Ci) is the function of river flow (W), emission of human activities (Pi) and background concentration of pollutants (Bi), which can be denoted as $C_i = f(W, P_i, B_i)$.

In this equation, river flow and background concentration are exogenous variables. Provided by emission allocation obtained by the optimum allocation model discussed in last chapter, we can compute the water quality of the cross-section to define the final environmental responsibility of each district in the watershed.

4. Definition of water quantity responsibility in the Huiahe watershed

4.1 Framework of allocation indicators of water rights

According to the water rights allocation established before, we get the allocation framework for Huaihe watershed as follows:

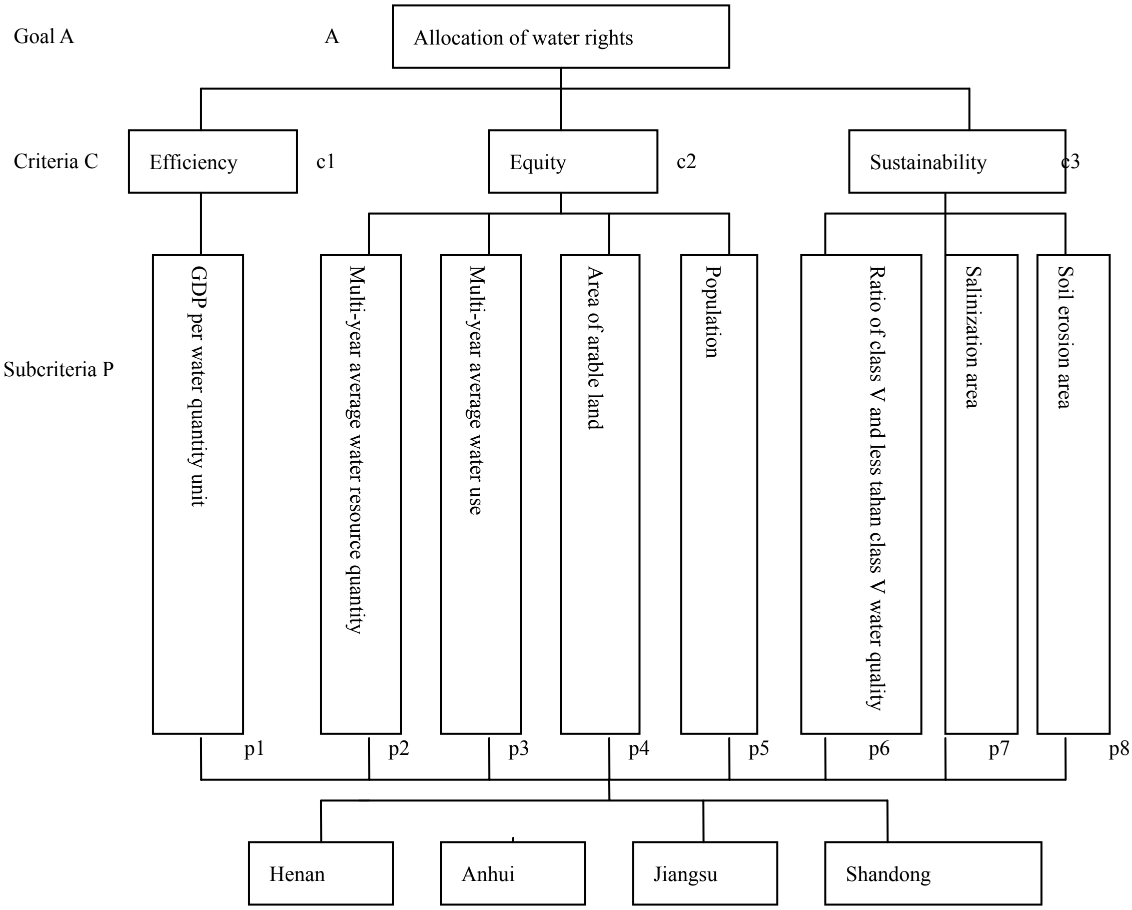

Figure 4.2 Hierarchy framework of allocation of water rights in Huaihe watershed

4.2 Determination of weight for indicators of water rights allocation

Authors invite experts in Water resource and hydroelectric institute and Hohai university to determine the weight. Through synthesizing the suggestions, the final judgment matrix is:

Table 4.6 judgment matrix for principle c2 (fairness)

c2	p2	p3	p4	p5
p2	1	2	3	4
p3	1/2	1	2	3
p4	1/3	1/2	1	2
p5	1/4	1/3	1/2	1

Table 4.7 judgment matrix for principle c3 (sustainability)

c3	p6	p7	p8
p6	1	5	3
p7	1/5	1	1/3
p8	1/3	3	1

Table 4.8 judgment matrix for overall objective

A	c1	c2	c3
c1	1	1/4	1/2
c2	4	1	3
c3	2	1/3	1

According to the weight experts assigned, and the weight of compensation capacity should be the same as the indicator of GDP per water quantity unit, thus we get the weight of each indicator as table 4.9, and weight vector is W = (0.2473，0.5932，0.4856，0.3976，0.3256，0.4275，0.192，0.2865)T，

Table 4.9 weight vector for each indicator

Multi-year average water resource quantity	Multi-year average water use	Area of arable land	Population in the Huaihe watershed	GDP per water quantity unit	Salinization area	Ratio of class V and less than class V water quality	Soil erosion area	GDP Per captia
0.5932	0.4856	0.3976	0.3256	0.2473	0.192	0.4275	0.2865	0.2473

4.3 Standardize the indicator matrix of water rights allocation

Our paper allocate the water resource of Huaihe watershed of year 2006, so the indicator data is from 2005, the indicator matrix of each province is as table 4.10. Our paper adopt linear scaling transformation method to standardize the matrix[15]

Table 4.10 Indicator matrix of each province in Huaihe watershed

	Multi-year average water resource quantity (10^8m^3)	Multi-year average water use (10^8m^3)	Area of arable land (10^3hectare)	Population in the Huaihe watershed (10^4people）	GDP per water quantity unit （yuan/m^3）	GDP Per captia (10^4yuan/people)	Salinization area (10^3hectare)	Ratio of class V and less than class V water quality	Soil erosion area (10^3hectare)
Henan	283.91	90.66	4313.89	5572.51	61.72365441	1.12980685	403.03	59%	2526.76
Anhui	276.25	92.62	2806.14	3832.2	22.69854557	0.87914949	111.46	62.4%	879.3
Jiangsu	249.81	202.59	3220.31	4003.98	23.39427634	2.45121318	664.91	61.21%	702.42
Shandong	148.10	74.52	2194.02	3341.49	55.23684211	2.00420717	318.51	60.5%	1853.95

Data source:《2005 Huaihe water resource bulletin》, water resource bulletin of each province in Huaihe watershed, 《2006 journal of treatment of Huaihe》

The method is: in the decision matrix $U=(u_{ij})_{m\times n}$, $u_j^* = \max_{1\le i\le m} u_{ij} \neq 0$, then $r_{ij} = \frac{u_{ij}}{u_j^*}$ $(1\le i\le m, 1\le j\le n)$. Matrix $R=(r_{ij})_{m\times n}$ is called standardized matrix, standardized indicators should be limited by the requirement; $0\le u_{ij}\le 1$

In our case, calculated standardized indicator matrix is as table 4.11,

Table 4.11 Standardize matrix

	Multi-year average water resource quantity	Multi-year average water use	Area of arable land	Population in the Huaihe watershed	GDP per water quantity unit	Salinization area	Reciprocal of GDP per capita	Ratio of class V and less than class V water quality	Soil erosion area
Henan	1	0.447505	1	1	1	0.606142	0.778141	0.945513	1
Anhui	0.97302	0.45718	0.650489	0.687697	0.36774468	0.167632	1	1	0.347995
Jiangsu	0.879892	1	0.746498	0.718524	0.379016385	1	0.358659	0.980929	0.277992
Shandong	0.521644	0.367837	0.508594	0.599638	0.89490557	0.479027	0.438652	0.969551	0.733726

Using following equation to calculate allocation matrix of water rights.

$$B = W^T \bullet R^T = [w_1, w_2, ..., w_m] \bullet \begin{bmatrix} r_{11} & \dots & r_{1m} \\ \dots & \dots & \dots \\ r_{n1} & \dots & r_{nm} \end{bmatrix} = [b_1, b_2, ..., b_n]$$

Standardize the vector B and we can get final allocation vector C

$$C = \frac{B}{\sum_{i=1}^{n} b\ i}$$

Then we can get final weight of each province for allocating water rights is C =（0.298865，0.234251，0.259225，0.207659）

5. Calculating the allocated water quantity of four procvinces

Consider that basic water use for residents'life should be firstly guaranteed, so in the water rights allocation process, residents' life use water should be given priority for satisfying. Therefore, the water quantity for allocation is the total water resource quantity minus basic water use for residents'life of all the regions minus ecological water use of the river course.

As to ecological water use of river course, the utilization ratio of rivers with abundant runoff should not surpass 40%, poor runoff rivers should not exceed 60%.Huaihe watershed is abundant runoff river, 40% is the utilization ratio

Due to the data of domestic water use quota of each province: Shandong: 102.5L/d , Henan: 100L/d, Jiangsu: 165L/d, Anhui: 185L/d.(Data is from 《water use quota 》of each province), water quantity that can be used for allocation is 482.96-82.83-482.96×60%=11.0354 billion m3 .Then allocated water rights of each province is：Henan, 3.298095 billion m3，Anhui,2.585053 billion m3，Jiangsu, 2.860652 billion m3，Shandong 2.2916 billion m3

If we allocate water rights according to the multi-year water use of each province, then the result of water allocation ratio should be : 0.1969，0.2012，0.44，0.1619。Range of variation is：+51.67%，+10.8%，-39.1%, +29.96%。

6. Conclusions and Prospects

The principle and indicator system of AHP should be improved，in addition, weight determination process should let water user participate for the sake of convenient implementation.

Equity is a concept hard to measure, so the indicator system for Gini coefficient method should be further studied.

How to certify the reasonable range for the Gini coefficient, and there are many methods for calculate Gini coeffient.

Another indicator “ negotiation ability” should be added in the allocation model, because upstream has the priority in water quality control as well as water quantity control. So the quantification of negotiation ability should be the research direction in the future.

Water quality and water quantity is the properties of water , these two properties are undetachable. So the method for integrating these two properties should be highly emphasized

Because the allocation of emission permit and water rights happens between the provinces in this thesis, if it happens between the smaller districts in one provinces, or even smaller than that, the efficiency indicators should be put more weight.

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