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The Research on Cooperation Coordination Model of Transboundary Water Pollution

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***Abstract*—At first this paper introduces some related research at home and abroad about lake basin transboundary water pollution, and puts forward several basic assumptions combining the lake basin situation such as pollutants artificial regulation and pollutant water separation disposal, etc. Then bases on this foundation, constructs the minimum cost of the whole region, and proposes the coordination model of the lake basin transboundary water pollution. Then takes advantage of Poyang Lake for empirical analysis, and gets the function of pollutant reduction cost and function of environmental damage cost by means of multiple regression analysis with the five main data of Poyang Lake from 2001 to 2010.And obtains the solution through the coordination model and the function, then by comparison finds the solution is better than the actual pollution reduction plan. At last, the paper talks about the deficiencies and improvement.**

***Keywords*—Cooperation model; Poyang Lake; Multiple regression; Transboundary; Environmental damage cost**

I. INTRODUCTION

River basin can be divided into the natural boundary and administrative boundary, natural boundary of river basin is natural hydraulic boundary in long time, whereas the administrative boundaries are artificially created for economic and social affairs management, and the scope of both two boundaries are not accordance. And because of this, many areas had conflicts of interest that cause pollution disputes, which affects the region's economic and social development seriously. For example, In Europe the Rhine flows through nine countries such as France, Switzerland, Germany, the Netherlands and so on, but cross-border pollution dispute emerge since the late 1950s. When it comes to 1980s,the water pollution makes the life and the production of the Rhine river downstream severely damaged. Let's turn to China, Shanxi aniline spill in 2013 caused some residents of Shanxi, Henan and Hebei provinces huge panic, even more bring to their production and life a lot of damage. However, the three provinces pass the buck to each other. Therefore, the transboundary water pollution dispute is a very difficult problem.

In order to solve this problem, many scholars have put forward their views.Ma and Hipel [1] put forward three criteria including force ability, deal execution and dispute handling to judge the advantage and disadvantage of transboundary water resources agreement. Barcena-Ruiz[2] talk about the upstream and downstream countries' environment tax issues. Vari and Tortajada[3] etc put effort into the analysis and research of the five great lakes of North America. The domestic study of transboundary water pollution started later,Yuxijun[4] take the Tai Lake basin for example to conduct the Yangtze river basin water ecological compensation mechanism research.Zhaolaijun[5] study the transboundary water pollution problem according to the structural characteristics of river basin,and propose three measures to solve the problem of transboundary pollution consist of administration, economic, market.This paper displays the cooperation coordination model of the Lake basin transboundary,and takes advantage of EKC curve to construct the damage cost of each area, then calculates the overall minimum environmental costs,and the last attains the best treatment plan of each region.

II. COOPERATION COORDINATION MODEL OF TRANSBOUNDARY WATER POLLUTION

According to the lake across the administrative region of the basin structure characteristics of the basin,the paper reveals the mechanism of lake basin across administrative region water pollution, and quantitative analysis of lake basin's water pollution across administrative region cooperation coordination model, and puts forward to promote lake basin water environmental governance countermeasures and suggestions to different regions.The regions surround the lake make up the Assemble I and all the kinds of pollutant make up the Assemble J. Now,we present several assumptions,and then describe the model.

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A. Assumption

Assumption 1: Each region of the lake basin is assumed to be a decision maker, who wants to minimize its own environmental cost. So we can think regional pollutant reduction cost function is independent of each other.

Assumption 2: Defferent pollutants could be abated separately. Though various kinds of pollutants can be dissolved in the same wastewater,it is reasonable to assume that different pollutants require different processing equipments and different handling procedures because different pollutants have different physical,chemical,or biological characterisitics.Therefore,the same wastewater can be disposed in different places for different types of pollutants to make full use of the cost-cutting advantages.

B. Variable definitions

Assumes that the lake basin surrounded by the i areas (i∈I,j∈J)：

P_{ij} represents the reduction of pollutant j for region i ;

P_{oij} represents the production of pollutant j for region i ;

P_{imax} represents the biggest bear ability under the certain criteria for the region I;

π_i represents the environment cost for the region I;

π_t represents the environment cost of all the region;

AC_{ij} represents pollutant reduction cost of the pollutant j for region i;

EC_j represents environment damage cost for the region i;

P_{iej} represents actual delivery of the pollutant j for region i.

C. Model description

The cooperation coordination model of lake basin transboundary water take advantage of economic measures to encourage each region to reduce pollutant cooperatively,and each region tries to seek optimum project to minimum the overall cost of the basin under administrative agencie policies. The regional environmental pollution cost mainly consists of the pollutant reduction cost(AC) and environment damagement cost(EC).

The regional environmental cost of the basin:

$$\pi_{ij} = AC_{ij} + EC_{ij}$$

The total environmental cost:

$$\pi_t = \sum_{i\in I, j\in J} \pi_{ij} = \sum_{i\in I, j\in J} AC_{ij} + \sum_{i\in I, j\in J} EC_{ij}$$

The regional water quality meets the national standard, the whole basin meet to the pollutant reduction index of the state. Regional pollutant reductions combined are equal to the quantity of the basin reduction under the nationan environment standard.

$$\sum_{i\in I, j\in J} P_{ij} = \sum_{i\in I, j\in J} P_{0ij} - \sum_{i\in I, j\in J} P_{iej}$$

Regional pollutant reductions is at least zero.

$$P_{ij} \geq 0$$

Set the handling capacity of sewage treatment facilities less than or equal to pollutants discharge.

$$P_{ij} \leq P_{0ij}$$

Thus, the model is as follows:

$$\begin{aligned} \min \pi_t &= \sum_{i\in I, j\in J} AC_{ij} + \sum_{i\in I, j\in J} EC_{ij} \\ s.t. \quad & \sum_{i\in I, j\in J} P_{ij} = \sum_{i\in I, j\in J} P_{0ij} - \sum_{i\in I, j\in J} P_{iej} \\ & P_{ij} \geq 0 \\ & P_{ij} \leq P_{0ij} . i \in I, j \in J \end{aligned}$$

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III. CASE STUDY

The Poyang Lake is the biggest fresh water lake which lies in the north of Jiangxi Province. The lake gets together the water of five main tributaries and injects into the Yangtze river. The Poyang lake basin has a very large area and its water is abundant. Nowadays, the Jiangxi Province devotes itself into the economic of the Poyang lake, and makes efforts to forge the Poyang lake basin to be the ecological economic demonstration area of central China areas.

However, the Poyang lake region also suffers serious environmental pollution in the development of economy.

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The monitoring data shows that in recent years the concentrations of TN, COD are on the rise, the area of level Ⅲ and level Ⅳ water is expanding and the whole area is in moderate eutrophication, even some regions has entered a severe eutrophication. Changes happened in the Poyang lake, which will have far-reaching influence on development of Poyang lake in the future. Through the study of this article, we can provide reduction plan of the Poyang lake basin pollution.

At first, the paper makes some explanations:

(1) Because the statistics are based on administrative division, it is easier to make sure the function of the whole basin than the partial region. Thus in the next study,the paper uses all the administrative data.

(2) There are three cities surrounding the Poyang lake ,which are Nanchang, Jiujiang and Shangrao. But according to statistics yearbook and other data, Shangrao information is too little to be in operation. So the paper mainly discuss the pollutant reduction between Nanchang and Jiujiang.

From 2002-2011 the China environment yearbook, we can collect the information of Nanchang and Jiujiang such as sewage treatment facilities operating cost, industrial waste water emissions, industrial wastewater treatment and so on. Then we select five kinds of pollutants consist of COD, Volatile Penol(VP), Ammonia Nitrogen(AN), Cyanide(C) and Petroleum(P) to analysis, and adopt the secondary emission standards in Table I.

TABLE I
THE SECONDARY EMISSION STANDARDS

Pollution	Secondary emission standards(mg/l)
COD	120
VP	20
AN	25
C	0.5
P	150

A. Pollutant reduction cost function estimate

According to Zhao et al.[6], this paper adopts the following cost function:

$$AC_i = AW^{B_1}P_i^{B_2},$$

Where ACi represents the reduction costs of pollutant I for region j; A,B_1,B_2 represents coefficient; Pi represents reduction quantity of pollutant i for region j; W represents Sewage emission.

Take the logarithm on both sides,

$$\ln AC_i = \ln A + B_1 \ln W + B_2 \ln P_i \cdot$$

Due to some data is not easy to get, we do the following process.

$$\frac{\eta_i}{\sum_{k=1}^{5}\eta_k} = \frac{\frac{E_i - I_i}{S_i}}{\sum_{k=1}^{5}\frac{E_k - I_k}{S_k}} = \frac{\frac{(E_i - I_i)\cdot W}{S_i}}{\sum_{k=1}^{5}\frac{(E_k - I_k)\cdot W}{S_k}}) = \frac{\frac{P_i}{S_i}}{\sum_{k=1}^{5}\frac{P_k}{S_k}}$$

The reduction cost of pollutant i is as follows:

$$AC_i = AC \cdot \frac{\frac{P_i}{S_i}}{\sum_{k=1}^{5}\frac{P_k}{S_k}}$$

Through the above process and application of SPSS,we could attain the following pollutant reduction cost function:

NanchangCOD： $AC_{ncCOD} = 0.00570W^{1.049}P^{0.504}$,

NanchangVP: $AC_{ncAP} = 0.00396W^{0.786}P^{0.932}$

NanchangAN: $AC_{ncAN} = 0.001615W^{0.637}P^{1.269}$

NanchangC: $AC_{ncC} = 5.089W^{0.161}P^{0.933}$

NanchangP: $AC_{ncP} = 0.0000106W^{0.951}P^{0.954}$

JiujiangCOD: $AC_{jjCOD} = 0.001314W^{1.564}P^{0.118}$

JiujiangVP: $AC_{jjVP} = 0.001448W^{1.315}P^{0.224}$

JiujiangAN: $AC_{jjAN} = 0.002007W^{0.711}P^{1.108}$

JiujiangC: $AC_{jjC} = 0.03868W^{1.130}P^{0.877}$

JiujiangP: $AC_{jjP} = 0.00002918W^{1.030}P^{1.004}$

B. The cost of environmental damage estimation

According to Baiqirui and Yangkaizhong's[7] study of relationship between economic growth and environmental pollution, there is a EKC curve relation between economic development and environmental pollution levels, that is to say the reverse "U" curve.

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Later, Lizhitao and Huangheqing[8] etc apply this theory to explore the relationship between economic development and water pollution in the Poyang lake basin. This article is fitting out a quadratic function of the emissions of pollutants and environmental damage on the basis of their study.

Nanchang EC function: $Yi = 0.0009Xi^2 - 14.357Xi + 54127$

JiujiangEC function: $Yi = 0.0016Xi^2 - 22.678Xi + 81573$

Y_i represent the environment damage cost of region i, X_i represent the pollutant emission of region i.

Through the check number,R^2-EC(Nc) is 0.8211 and R^2-EC(Jj) is 0.9844, shows they have good statistical significance.

Through the above process,we can get the models of each pollutant with the data of 2010.

$$\begin{aligned} \min\ \pi_{COD} &= 248.51P_n^{0.504} + 8078.87P_j^{0.118} + 0.0009(40590 - P_n)^2 - 14.357(40590 - P_n) \\ &\quad + 0.0016(26523.9 - P_j)^2 - 22.678(26523.9 - P_j) + 81573 \\ \text{s.t.}\quad & P_n + P_j \ge 35632.8, \\ & 0 \le P_n \le 36531, 0 \le P_j \le 23871.51. \end{aligned}$$

$$\begin{aligned} \min \pi_{VP} &= 11.86P_n^{0.932} + 739.10P_j^{0.224} + 0.0009(219.93 - P_n)^2 - 14.357(219.93 - P_n) \\ &\quad + 0.0016(308.45 - P_j)^2 - 22.678(308.45 - P_j) + 81573 \\ \text{s.t.}\quad & P_n + P_j \ge 518.2, \\ & P_n \le 219.93, P_j \le 308.45. \end{aligned}$$

$$\begin{aligned} \min \pi_{AN} &= 1.06P_n^{1.269} + 2.193P_j^{1.108} + 0.0009(3478.5 - P_n)^2 - 14.357(3478.5 - P_n) \\ &\quad + 0.0016(1124.1 - P_j)^2 - 22.678(1124.1 - P_j) + 81573 \\ \text{s.t.}\quad & P_n + P_j \ge 2606.8, \\ & P_n \le 3128.22, P_j \le 1011.69. \end{aligned}$$

$$\begin{aligned} \min \pi_C &= 26.22P_n^{0.933} + 3107P_j^{0.877} + 0.0009(148.3 - P_n)^2 - 14.357(148.3 - P_n) \\ &\quad + 0.0016(0.1 - P_j)^2 - 22.678(0.1 - P_j) + 81573 \\ \text{s.t.}\quad & P_n + P_j \ge 145.9, \\ & P_n \le 148.3, P_j \le 0.1. \end{aligned}$$

$$\begin{aligned} \min \pi_P &= 0.17P_n^{0.954} + 0.86P_j^{1.004} + 0.0009(4711.9 - P_n)^2 - 14.357(4711.9 - P_n) \\ &\quad + 0.0016(871.8 - P_j)^2 - 22.678(871.8 - P_j) + 81573 \\ \text{s.t.}\quad & P_n + P_j \ge 5454.3, \\ & P_n \le 4711.9, P_j \le 871.8. \end{aligned}$$

Through calculation of the software, we can get optimal reduction quantity as follows:

TABLE III
COMPARISON

	COD	VP	AN	C	P
The optimal reduction quantity of Nanchang	32210	220	2481	146	4712
The optimal reduction quantity of Jiujiang	19388	298	126	0	742
The minimum cost of the model	16499	85798	123261	84276	79864
Actual environment al costs	23825 4	85811	123766	84276	80378

Now we find the model answer is better than the current actual amount pollutant reduction. So it can offer us a better reference in the pollution control scheme.

IV. CONCLUSION

Through the above empirical analysis, the lake basin transboundary water cooperation coordination model has more instruction value compared with the current actual amount pollutant reduction.So that it provides better reference for watershed management institutions.However, we also have to see some impact factors that restrict the model to obtain the best reduction.

C. Cost function of the goodness of fit problem.

This article adopts the environmental yearbook data of ten years from 2001 to 2010, the regression equation of five kinds of pollutants while has a better goodness-of-fit, but still need to improve. And due to limited data samples is less. Therefore we need to accumulate more time environment statistics, further improve the regional various pollutant reduction cost function fitting result.

D. Information asymmetry problem.

Various regions provide false information for their own sake. Thus river basin administrative agencies will not be able to get the optimal reduction plan.Therefore, it is important for the administrative to ensure the statistic information reality,otherwise this process will be invalid.

E. The time lag problem of regulation and control policy.

From collecting information, confirmation, measurement, monetisation, policy making, policy implementation, an environmental regulation policy needs a long process. And the river basin administrative agencies regulation and control policies should maintain stability. But the market is changing, optimal cutting quantity at this time is not the optimal plan while at that time. So these processes need to keep timeliness.

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