Assessment of Economic Loss Caused by Agricultural Non-point Source Nutrient Loss

FAN Liang-qian[1,2], **CHEN Feng-hui**[1*]

1. Urban and Rural Development College, Sichuan Agricultural University, Dujiangyan 611830, China; 2. College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, China

Abstract Taking Zhejiang Province as an example, we use the JOHNES export coefficient model to estimate the total nitrogen (TN) and total phosphorus (TP) load of agricultural planting, livestock and poultry breeding and rural living non-point source in 2009. Based on the protection cost method in environmental economics, we quantitatively assess the economic loss caused by these three types of non-point source nutrient loss. The results show that in TN non-point source load, the load of land for planting accounts for 57.48%, the load of rural living accounts for 30.22%, and the load of livestock and poultry breeding accounts for 12.30%; in TP non-point source load, the load of rural living accounts for 46.18%, the load of livestock and poultry breeding accounts for 29.00%, and the load of land for planting accounts for 24.82%. The economic loss arising from the agricultural non-point source nutrient loss is equivalent to 2.329 424 7 billion yuan per year (the loss from land for planting accounts for 55.46%; the loss from rural living accounts for 31.21%; the loss from livestock and poultry breeding accounts for 13.33%). It indicates that in order to reduce the loss arising from agricultural non-point source nutrient loss, we should pay attention to controlling the land for planting and rural living source.
Key words Agricultural non-point source, Water environment, Economic loss, Total nitrogen, Total phosphorus

30% to 50% of the surface in the world has been affected by non-point source pollution, and non-point source pollution is mainly from agricultural activities[1-2]. China is a large agricultural country, and agriculture is the main pillar in the rapid social and economic development. As the intensive level of agricultural production is low, the agricultural non-point source arising from considerable unused chemical fertilizer and livestock manure is bound to pose a significant threat to surface water environmental safety. In this environment, there has been a large number of scholars conducting researches on relevant issues concerning China's agricultural non-point source. For example, Chen Yuanyuan *et al.*[3] analyzed the relevant data on the downstream irrigation area of the Yellow River in recent years, and gave an overview of the major reason for the agricultural non-point source pollution in this area. Using AnnAGNPS model, Zhao Qian *et al.*[4] conducted estimation on the load of agricultural non-point source pollution in Chaihe upstream watershed. Taking the Daning River valley in the Three Gorges Reservoir Area as the study area, Fan Lili *et al.*[5] calculated the load of agricultural non-point source pollution in the valley, using the SWAT model. Dai Caijiang *et al.*[6] introduced the concepts and principles of best management practices (BMPs), gave an overview of its application to agricultural non-point source pollution control in the valley from engineering and management measures, and pointed out the problems of BMPs in the valley water quality management. Although these studies clarify the source, contribution, pollution and governance program of agricultural non-point source, it lacks the researches on economic loss assessment in terms of agricultural non-point source management. Based on the status quo of China's agricultural non-point source, the effective assessment of economic loss arising from agricultural non-point source is the basis of water environmental planning and water environmental policies, and also the main content of green national economic accounting. In addition, carrying out the relevant researches on assessment of economic loss caused by agricultural non-point source can help improve the public awareness of issues concerning agricultural non-point source, so that people actively participate in water environmental protection, to achieve sustainable use of water resources[7].

Taking the case of Zhejiang Province, we use the JOHNES export coefficient model to estimate the total nitrogen (TN) and total phosphorus (TP) load of agricultural planting, livestock and poultry breeding and rural living non-point source in 2009. Based on the protection cost method in environmental economics, we quantitatively assess the economic loss caused by these three types of non-point source nutrient loss, in order to provide scientific basis for the governance and control of agricultural non-point source pollution.

1 Overview of the study area

Zhejiang Province is located along the southeast coast of China, the south wing of the Yangtze River Delta, which consists of 11 prefecture-level cities, with a total area of 105 400 million hm^2, of which the area of agricultural land is 86 700 hm^2 (arable land accounts for 22.2%, garden plot 7.6%, woodland 64.9%). In 2009, the permanent population reached 47.161 8 million, of which the agricultural population was 32.822 3 million, and the population engaged in the primary industry was

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* Corresponding author. E-mail: cfenghui@yahoo.com

6.579 5 million. The average annual precipitation is 1 640 mm, concentrated in April – September. Uneven precipitation results in serious soil erosion. The soil nutrients and sediment flow into water body with soil erosion, causing water pollution. Some existing research results show that at present, the agricultural non-point source pollution in some areas of Zhejiang Province is serious; the agricultural non-point source is mainly from livestock and poultry breeding, rural living and farming[8-11].

2 Research methods

2.1 Estimation method of agricultural non-point source pollution load Some of the existing research results show that the agricultural non-point source pollution in some areas of Zhejiang Province is serious, and the agricultural non-point source is mainly from livestock and poultry breeding, rural living and agricultural planting[8-11]. The economic loss caused by agricultural non-point source nutrient loss should be assessed based on the data of load of agricultural non-point source nutrient pollution. Therefore, we should first estimate the load of agricultural non-point source nutrient. There are many methods for estimating the load of agricultural non-point source, of which the export coefficient model is convenient and practical, having simple structure. There is little data needed by the model, and the data is easily accessible. In addition, the model takes year as period to directly assess and predict the load of pollutants, and rarely touches upon the specific existing form of pollutants, thereby reducing a lot of tedious research processes, and greatly improving the reliability of the model results[12]. Therefore, this study selects the most widely used JOHNES export coefficient model at present[13] as a method for estimating the load of agricultural non-point source.

JOHNES model divides arable land in accordance with the cultivation methods, and different cropping patterns are corresponding to different export coefficients; different export coefficients are used for different categories of livestock; the export coefficient of population-producing pollution is selected based on lifestyle and treatment pattern of pollutants. In addition, JOHNES model also considers the load of pollutants generated by the air settlement and other factors, further improving the content of the export coefficient model. The concrete JOHNES model is as follows:

$$L = \sum_{i=1}^{n} E_i [A_I(I_i)] + P \quad (1)$$

where L is pollution load (kg); E_i is the export coefficient of type i pollutant, namely the annual export amount of pollutants per unit area (kg/hm^2·a), or the annual export amount of pollutants from per head of livestock (kg/head·a) and domestic pollution (kg/person·a); A_i is the area of category i land use type (hm^2) or the number of type i livestock and poultry, population; I_i is the pollutant amount of type i sources of pollution (kg) per unit area or from manure per head of livestock and domestic pollution; P is the amount of pollutants arising from air settlement. The amount of pollutants from air settlement is ignored in the study.

From three aspects (agricultural planting, livestock and poultry breeding and rural living pollution emissions), we estimate the TN and TP load of agricultural non-point source pollution in Zhejiang Province in 2009.

2.2 Export coefficient

2.2.1 Export coefficient of land for agricultural planting. Based on *Zhejiang Statistical Yearbook* in 2009, we divide the land for agricultural planting into paddy field, dry land, orchard, woodland for estimation in the process of calculation. The pollutant export coefficient of different land for agricultural planting is shown in Table 1[14].

Table 1 TN and TP export coefficients of different land for agricultural planting kg/hm^2·a

Pollutants	Paddy field	Dry land	Woodland	Tea garden and orchard
TN	34.10	7.59	3.10	19.91
TP	1.75	0.64	0.15	1.51

2.2.2 Export coefficient of livestock and poultry breeding. The TN and TP pollution from livestock and poultry breeding is mainly generated by feces and urine excretion of the livestock. Excretion of livestock manure and urine is related to livestock species, growth period, feed and many other factors, so it is of regional feature. After researching and referring to the relevant data, we determine the TN and TP export coefficient of different breeding types of livestock and poultry (Table 2)[8]. The major animal raised in Zhejiang Province is pig, poultry, cattle, and sheep.

Table 2 TN and TP export coefficients of different types of livestock kg/head · a

Pollutants	Cow dung	Cow urine	Pig urine	Pig manure	Poultry manure	Sheep manure
TN	6.79	6.21	0.50	0.46	0.06	0.49
TP	1.33	0.22	0.21	0.05	0.02	0.07

The manure pollutants of livestock and poultry can not all enter into the environment, so there is a great difference in the degree of loss in different regions under different management levels. Literature suggests that the loss rate of animal manure in the water body is as follows: feces remain at the level of 2% to 8%, while liquid excreta may reach 50%[15]. Due to lack of relevant information, in the calculation process, the fecal loss coefficient is taken at 8%, and urine loss coefficient at 50%.

2.2.3 Export coefficient of rural living. Population distribution in rural areas is much sparser than that in urban areas. And pollutant treatment facilities are not sound, thus the pollutants discharged everywhere form area-source pollution in a certain sense. In general, rural living pollutants are mainly generated by the discharge of excreta and sewage. The rural living pollutants are generated in the same way, but because of the different regional habits, there are differences in the nitrogen, phosphorus content of excreta and sewage. Therefore, this study uses literature[8] to determine the rural living export coefficient. The TN, TP export coefficients of sewage and excreta are 0.584 kg/person · a, 0.146 kg/person ·a; 0.306 kg/person· a, 0.0524 kg/person ·a. The excreta can not all enter the water body, so in determining the export coefficient, the excreta is estimated based on loss rate of 10%[8].

2.2.4 Basic data. For the basic data on agricultural planting, livestock and poultry breeding, rural living pollution emissions, we obtain them based on *Zhejiang Statistical Yearbook* in 2010. The concrete data can be shown in Table 3.

Table 3 Agricultural non-point source pollution-producing basic data in Zhejiang Province in 2009

Type	Land type	Area $\times10^3$ hm^2	Type	Livestock and poultry species	Number $\times10^4$ head)
Land for planting	Paddy field	979.43	Livestock and poultry breeding	Pig	3 119.8
	Dry land	1 854.96		Cow	27.4
	Woodland	163.86		Poultry	38 373.84
	Tea garden and orchard	377.68		Sheep	214.4
Rural population		3 279.06 (10^4 people)			

2.3 Loss assessment For different types of non-point source pollution, the loss assessment methods are different. As to the TN, TP nutrient loss, we can assess it using the protection cost method[16]. In the environmental economic loss assessment, the protection cost method is the commonly used indirect algorithm for the economic evaluation of environmental degradation. In accordance with the expenditure prepared by people for preventing environmental degradation, it infers the people's valuation of environmental values. The specific evaluation formula is as follows:

$$S_i = \sum T_i \times K_i \times C \quad (2)$$

where S_i is the value loss (yuan) caused by the loss of nutrient i (i is TN or TP); T_i is the total loss of nutrient i arising from non-point source pollution (t); K_i is the coefficient of nutrient i being converted into diammonium phosphate (the coefficient of N and P being converted into diammonium phosphate is 9.43 and 4.26, respectively); C is the market price of diammonium phosphate (yuan) (according to the survey, the market price of diammonium phosphate in Zhejiang Province is 2 400 yuan/t in recent years).

There are some unfavorable factors in the use of the protection cost method to assess the economic loss arising from TN, TP loss. Because the method assumes that people understand the extent of environmental risk, respond accordingly, and corresponding actions taken are less likely to be constrained by some factors, such as poverty or market imperfections, but people often tend to overestimate or underestimate the compensation that they want, thus affecting the accuracy of the evaluation results.

3 Results and analysis

3.1 Estimation results of agricultural non-point source nutrient load Estimation results of agricultural non-point source TN and TP pollutant load in Zhejiang Province in 2009 can be shown in Table 4. It can be seen from Table 4 that total agricultural non-point source TN, TP load is 96 562.10 t and 14 087.57 t, respectively. In the TN non-point source load, the generation amount of land for planting is the greatest, accounting for 57.48% of the total load, of which the paddy field has the greatest contribution rate at 60.17%; the generation amount of rural living is in the second place, accounting for 30.22%; the generation amount of livestock and poultry breeding is the smallest, accounting for 12.30%, of which pig breeding has the greatest contribution rate at 75.36%. In the TP non-point source load, the generation amount of rural living is the greatest, accounting for 46.18% of the total load; the generation amount of livestock and poultry breeding is in the second place, accounting for 29%, of which the contribution rate of pigs is 83.23%; the generation amount of land for planting is the smallest, accounting for 24.82%, of which the contribution rate of paddy field and dry land is 49.03% and 33.96%, respectively. The results show that for the control over agricultural non-point source TN, we should pay attention to land for planting, and farming in paddy field should be regarded as focus; for the control over agricultural non-point source TP, we should focus on rural living.

3.2 Economic loss arising from agricultural non-point source nutrient loss Table 5 gives the estimated economic loss arising from agricultural non-point source nutrient loss in Zhejiang Province in 2009.

It can be seen from Table 5 that in the total economic losses arising from agricultural non-point source TN, TP loss in Zhejiang Province in 2009, the economic loss from land for planting is the greatest, equivalent to 1 291.939 2 million yuan, accounting for 55.46% of the total economic losses, followed by rural living, equivalent to 726.997 8 million yuan, accounting for 31.21% of the total economic losses; the economic loss from livestock and poultry breeding is the smallest, equivalent to 310.487 7 million yuan, accounting for 13.33% of the total economic losses. In the economic loss caused by land for planting, paddy field and dry land account for 59.86% and 25.60%, respectively; in the economic loss caused by livestock breeding, pig breeding accounts for 76.42%.

Table 4 Estimation results of agricultural non-point source TN and TP pollutant load in Zhejiang Province in 2009 $\times10^3$ kg

Type	Land type	TN	TP	Type	Livestock and poultry species	TN	TP
Land for planting	Paddy field	33 398.56	1 714.00	Livestock and	Pig	8 947.59	3 400.58
	Dry land	14 079.15	1 187.17	poultry breeding	Cow	999.61	59.29
	Woodland	507.97	24.58		Poultry	1 841.94	613.98
	Tea garden and orchard	7 519.61	570.30		Sheep	84.04	12.01
Rural living		29 183.63	6 505.66				

The developed countries stipulate the safe upper limit of fertilizing amount per hectare of farmland on the average at 225 kg/hm² [17]. According to *Zhejiang Statistical Yearbook* in 2010, the fertilizing amount per hectare of farmland on the average in Zhejiang Province in recent 3 years is greater than 370 kg/hm². Although safe fertilizing amount is closely related to crop and soil, the current fertilizing amount in Zhejiang Province is far greater than the safety limit of the developed countries. Excessive fertilization leads to poor fertilizer effect, and serious loss of TN, TP nutrient, which is the most principal reason for the greatest economic loss from land for planting in the agricultural non-point source economic loss in Zhejiang Province. Thus reducing the use of phosphorus fertilizer, rationally developing and using organic fertilizer, and adopting zero wastewater discharge management in farming, is an important way to effectively reduce non-point source economic loss from land for planting[18-19]. According to the estimation of *Zhejiang Statistical Yearbook* in 2010, the population density of Zhejiang Province is roughly 509 /hm², approximately four times more than the national average population density. Although Zhejiang Province is economically developed, the township sewage treatment facilities are imperfect, thus the agricultural non-point source economic loss caused by rural living is huge. In order to reduce the non-point source economic loss from rural living, it is necessary to improve urban sewage collection pipe network, and speed up the study on sewage treatment technology in rural areas. In the course of the study, we do not take into account the ecological economic loss caused by soil erosion (sediment loss, abandoned land caused by soil erosion), aquaculture, atmospheric deposition and other factors. The land use only considers land for agricultural planting (paddy field, dry land, orchard, woodland), the grassland not considered. Therefore, in the study, the economic loss estimated arising from agricultural non-point source nutrient loss is lower than the actual economic loss.

Table 5 Agricultural non-point source economic loss in Zhejiang Province in 2009 10^4 yuan

Type	Type	TN	TP
Land for planting	Paddy field	75 587.62	1 752.39
	Dry land	31 863.93	1 213.76
	Woodland	1 149.64	25.13
	Tea garden and orchard	17 018.38	583.07
Livestock and poultry breeding	Pig	20 250.19	3 476.75
	Cow	2 262.32	60.62
	Poultry	4 168.68	627.73
	Sheep	190.2	12.28
Rural living		66 048.39	6 651.39
Total		232 942.47	

4 Conclusions

In TN non-point source load in Zhejiang Province in 2009, the generation amount of land for planting was the greatest, accounting for 57.48% of the total load; in TP load, the generation amount of rural living was the greatest, accounting for 46.18% of the total load. Therefore, in order to prevent agricultural non-point source TN and TP pollution, we should pay attention to controlling the land for planting and rural living source. Using the protection cost method in environmental economics, it is estimated that the economic loss arising from a year of agricultural non-point source nutrient loss in Zhejiang Province is equivalent to 2 329.424 7 million yuan. The economic loss from land for planting is the greatest, equivalent to 1 291.939 2 million yuan, accounting for 55.46% of the total economic losses, followed by rural living, equivalent to 726.997 8 million yuan, accounting for 31.21% of the total economic losses. It shows that the economic loss caused by nutrient loss in land use and rural living in Zhejiang Province is huge. Rationally optimizing the land use patterns, developing and using organic fertilizer, promoting new agricultural cultivation technologies, and improving the township sewage treatment system, is an effective way to reduce the economic loss arising from agricultural non-point source nutrient loss.

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(To page 77)

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(From page 70)

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