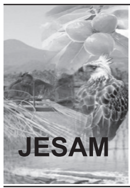

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A Watershed-Based Water Environment Eco-compensation Mechanism: a Case Study of Taihu Lake Basin, China

ABSTRACT

In 2008, a simple punitive eco-compensation method was implemented in the Taihu pilot region, China. However, due to the use of a flawed formula and weak compensation criterion the payments were considered unsuitable. To improve the scheme, the following issues were considered: determination of compensation criterion; compensation when water quality is acceptable; consideration of reciprocating flow; control of the errors in pollutant fluxes due to the non-synchronization of river flow and water quality data. Two alternative ways to calculate eco-compensation payments were assessed for a case study in 2013: a payment based on the "Water quality exceedance rate (WQER) method" was found to be 172 million CNY (24.9 million USD). This method avoided errors caused by the pollutant flux and considered the situations of reciprocating flow and acceptable water quality; and the "Pollutant treatment cost (PTC) method" was considered suitable for immediate implementation, although the payment was higher at 245 million CNY (35.4 million USD). The determination of compensation criterion using this method had a scientific basis, but it required perfect and reliable monitoring data. If these conditions are met, the method was considered suitable for future implementation.

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Key words: *Eco-compensation payment, Taihu pilot region, Water quality exceedance rate method, Pollutant treatment cost method*

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INTRODUCTION

The implementation of eco-compensation is an attempt to directly link ecosystem damage and economic activity (*Kangas and Ollikainen 2019*). Eco-compensation schemes strengthen government's environmental responsibility through economic means and pollution control initiatives, so promoting the continuous improvement of the regional environment. Many countries have issued eco-compensation regulations, such as the US no-net-loss policy for wetlands in the *Clean Water Act* (*1986*) and the Dutch compensation principles for spatially protected areas (*1993*). In 2008, river eco-compensation became a major amendment in the Laws of the People's Republic of China on Prevention and Control of Water Pollution. The implementation of water resource management was an early attempt at river eco-compensation, but this only focused on water volume (*Rosegrant and Binswanger 1994*) or was based on a transferable discharge permission certificate focusing on water quality (*Gouyon 2003; Liu et al. 2000*). In recent decades, studies have been conducted to determine an appropriate compensation method, the basis of the compensation standard, and payment, level (*Chen and Ma 2017; Ma 2018; Yu et al. 2020*). Several methods, such as the water pollution loss value method (*Guan et al. 2019*), the ecological footprint method (*Xiao et al. 2015*), the overflow accounting and cost-based a ccounting method (*Geng et al. 2018; Liu and Wang 2017; Sun et al. 2013*), the contingent valuation method (*Guan et al. 2016; Zhou et al. 2015*), the compensation computation method based on water quality and volume (*Xu et al. 2008*), and the water environmental capacity method (*Pang et al. 2010*) based on numerical models such as WASP (*Hosseini et al. 2016*), SWAT (*Boskidis et al. 2012; Rahman et al. 2012; Santosh et al. 2010*), Delft-3D (*Chen and Mynett 2006*), EFDC (*Li et al. 2011*), and MIKE (*Poulin et al. 2009*), have been considered for use as river eco-compensation methods, but they cannot be applied across the whole of a regional river network.

Some studies have been undertaken in the river network of the Taihu pilot region, where compensation payments have been calculated using a method based on an excessive pollutant flux that exceeds the water quality target. The calculation was as follows:

$$\sum (C_i - C_s) \times Q \times B \quad (1)$$

where C_i is the concentration of a pollutant based on water quality monitoring, C_s is the water quality target, Q is the water volume, and B is a punitive compensation criterion, i.e., chemical oxygen demand (COD) is 15,000 CNY (2,170 USD) per ton and ammonia nitrogen (NH_4^+–N) and total phosphorus (TP) are both 100,000 CNY (14,467 USD) per ton. If the water quality concentration exceeds the control target, an upstream city should financially compensate a downstream city or provincial government (for example, in the situation of a river flowing into a public water body, such as Taihu Lake or the Yangtze River). Although this eco-compensation method takes both the pollution flux and water quality into account, there have been many problems in its implementation, including: the weak compensation criterion led to payments being too low at 26 million CNY (3.76 million USD), which only accounted for 0.02% of municipal environmental investments (3% of the annual GDP); failure to consider the situation in which river retention or reciprocating flow and the water quality of the compensated site were up to standard; and the significant errors in pollutant flux caused by non-synchronization of river flow and water quality data, which led to unreasonable compensation payments. Given that this method has several deficiencies, its implementation has not been successful, and therefore environmental managers have sought to develop a more effective method.

The river network in the Taihu pilot region is complicated because of the uncertainty surrounding the flow direction and disturbances due to external conditions. Identifying who is responsible for pollution is difficult and habitat loss is difficult to calculate. In consideration of the shortcomings of the eco-compensation method based on an excessive pollutant flux, two effective and efficient compensation procedures were considered in this study, which were suitable for short- and long-term use, respectively. This case study will have a far-reaching influence on the coordination and guidance of environmental issues in river network regions, and is expected to provide a reference for the improvement of watershed based water eco-compensation systems.

MATERIALS AND METHODS

Study area

The Taihu Lake Basin is located in the southern part of the Yangtze River Delta in China, with a total area of 3.69 × 10^4 km^2. Taihu pilot region is located in the basin and covers the five main prefecture-level cities of Changzhou, Wuxi, Suzhou, and parts of Nanjing and Zhenjiang. The basin has a complicated river network system, with a river density of 3.24 km^{-2} and total river length of 1.2 × 10^5 km. The hydrographic net in Taihu Lake Basin in Jiangsu Province (**Figure 1**) consists of three rivers (the Grand Canal, the Wangyu River, and the Taipu River) and a series of parallel independent rivers flowing into the Yangtse River or the East China Sea. The basin accounts for only 0.4% of the national land of China, but its water supply service exceeds 33 million people accounting for 5% of the national population, with over 10% of the country's GDP is generated in the region and a per capita GDP that is 2.5 times the national average level.

In 2013, the total water resource in the Taihu pilot region was about 15 billion m^3, with the largest volume in Suzhou, followed in order by Nanjing, Wuxi, Changzhou, and Zhenjiang. The total water resources were 4.55, 3.07, 2.92, 2.91, and 1.52 billion m^3, respectively. The total GDP of each city was 1 300, 801, 807, 436, and 293 billion CNY (188, 116, 117, 63, and 42 billion USD), respectively. After a preliminary analysis, the highest water consumption per unit GDP was found to occur in Zhenjiang, with a value of 92 t per 10,000 CNY (1,447 USD), followed by Suzhou at 64.9 t per 10,000 CNY (1,447 USD). Wuxi was the lowest at 43.3 t per 10,000 CNY (1,447 USD). The resident population of the cities in 2013 was 10.5 million in Suzhou, 8.2 million in Nanjing, 6.5 million in Wuxi, 4.6 million in Changzhou, and 3.1 million in Zhenjiang. The top three cities in terms of per capita disposable income of urban residents were Suzhou at 58,750 CNY (7,890 USD), Nanjing at 54,538 CNY (8,500 USD), and Wuxi at 52,659 CNY (7,618

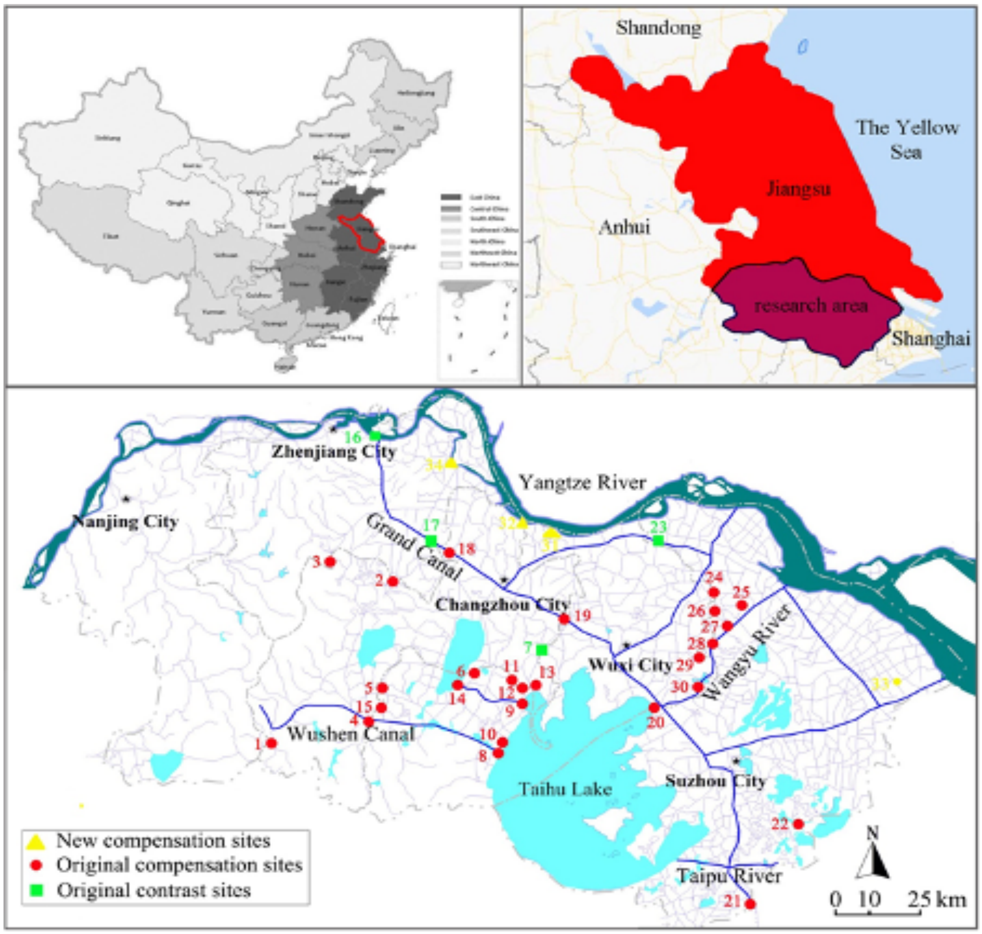

Figure 1. The hydrographic net system and water environment eco-compensation sites in the Taihu Lake Basin of Jiangsu Province, China.

USD). The differences in per capita income between the cities of the Taihu pilot region were not large.

Compensation sites

In 2007, the Environmental Protection Department of Jiangsu Province implemented a scheme named "Environmental resources compensation in the pilot region of Taihu watershed in Jiangsu Province, China". A total of 30 compensation sites were established in the scheme. As the economy developed, by 2013 the water quality in some rivers with large flows had deteriorated and four new river compensation sites were added (**Figure 1**).

Data sources

The Taihu pilot region includes five cities, but data acquisition has proven difficult. Payment is mainly determined by compensation criterion, together with water quality and flow data. Under the conditions of a constant compensation criterion, the difference in payments made between months over a short-term (several years) period is much larger than the difference in payments between years. Therefore, this study considered the full year of 2013 as a case study and monthly compensation payments were calculated. River flow and water quality data were provided by the Jiangsu Environmental Monitoring Station. The river flow data was the monthly average value of each compensation site in 2013, and the water quality data was the daily measured value of each compensation site in 2013.

The compensation direction of City A→ City B means City A makes a payment to City B (**Table 1**). The water quality target was determined from the Chinese "Environmental quality standards for surface water (GB3838-2002)", which are applied as a national standard.

Eco-compensation methodology

Water quality exceedance rate method (WQER method). Water environment eco-compensation in the Taihu pilot region is implemented mainly in the form of financial compensation between municipal governments.

Table 1. The compensation direction, water quality target, and average annual concentration of key pollutants at each compensation site.

Site number	Site name	River	Administrative district	Compensation direction	Water quality target	*COD*		*NH_4^+-N*		*TP*		Remark
						Average concentration ($mg \cdot L^{-1}$)	Excess standard rate	Average concentration ($mg \cdot L^{-1}$)	Excess standard rate	Average concentration ($mg \cdot L^{-1}$)	Excess standard rate	
1	Luopeng Bay	Xu River	Nanjing→ Changzhou	Nanjing→ Changzhou	Ⅲ	5.13	25%	0.61	8%	0.12	0%	original
2	White Pagoda	Danjinlicao River	Zhenjiang→ Changzhou	Zhenjiang→ Changzhou	Ⅲ	5.19	17%	0.73	17%	0.26	75%	original
3	Ziyang Bridge	Tongji River	Zhenjiang→ Changzhou	Zhenjiang→ Changzhou	Ⅲ	5.43	17%	0.93	42%	0.32	42%	original
4	Panjia Dam	Nanxi River	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	5.13	25%	1.03	42%	0.12	0%	original
5	Shanqian Bridge	Beixi River	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	5.88	25%	0.95	42%	0.1	0%	original
6	Zhongxi Bridge	Wuyi Canal	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	5.1	8%	1.28	50%	0.27	100%	original
7	Dongjian Bridge	Xilicao River	Wuxi→ Changzhou	Check Site of Fenshui	Ⅲ	5.11	8%	1.1	50%	0.32	100%	original
8	Chendong Harbor	Chendong Harbor	Wuxi→ Taihu Lake	Wuxi→ Province	Ⅲ	5.58	17%	0.98	33%	0.19	25%	original
9	Yincun Harbor	Yincun Harbor	Wuxi→ Taihu Lake	Wuxi→ Province	Ⅲ	3.98	0%	1.2	58%	0.2	33%	original
10	Guandu Harbor	Guandu Harbor	Wuxi→ Taihu Lake	Wuxi→ Province	Ⅳ	4.81	0%	1.08	58%	0.18	25%	original
11	Caoqiao	Caoqiao River	Wuxi→ Changzhou	Wuxi→ Changzhou	Ⅲ	4.47	0%	1.79	67%	0.34	100%	original
12	Peijia	Caoqiao River	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	4.9	25%	1.64	67%	0.3	100%	original
13	Fenshui	Taige Canal	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	4.46	0%	0.89	33%	0.2	33%	original
14	Heqiao Water Plant	Gehu Lake	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	6.06	33%	0.59	0%	0.09	0%	original
15	Tangdong Bridge	Youfang River	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅲ	5.69	33%	0.53	17%	0.05	0%	original
16	Jianbi	Beijing-Hangzhou Grand Canal	Yangtze River→ Zhenjiang	Check Site of Jiuli	Ⅲ	1.88	0%	0.69	17%	0.11	0%	original
17	Lvcheng	Beijing-Hangzhou Grand Canal	Zhenjiang→ Changzhou	Check Site of Jiuli	Ⅲ	3.54	0%	0.71	17%	0.17	8%	original
18	Jiuli	Beijing-Hangzhou Grand Canal	Zhenjiang→ Changzhou	Zhenjiang→ Changzhou	Ⅲ	3.04	0%	0.84	33%	0.21	50%	Original
19	Wumu	Beijing-Hangzhou Grand Canal	Changzhou→ Wuxi	Changzhou→ Wuxi	Ⅳ	5.91	0%	1.92	58%	0.37	58%	original
20	Wangting	Beijing-Hangzhou Grand Canal	Wuxi→ Suzhou	Wuxi→ Suzhou	Ⅳ	3.82	0%	1.09	17%	0.07	0%	original
21	Wangjiangjin g	Beijing-Hangzhou Grand Canal	Suzhou→ Zhejiang Province	Suzhou→ Province	Ⅲ	4.76	0%	1.14	67%	0.12	0%	original
22	Jishuigang Bridge	Jishuigang	Suzhou→ Shanghai	Suzhou→ Province	Ⅳ	3.51	0%	0.84	0%	0.17	0%	original
23	Yuanjia Bridge	Zhangjiagang River	Suzhou→ Wangyu River	Check Site of Fenghuang	Ⅳ	6.33	0%	1.98	67%	0.25	25%	original
24	Fenhuang	Zhangjiagang River	Wuxi→ Suzhou	Wuxi→ Province	Ⅳ	3.58	0%	1.55	50%	0.13	0%	original
25	Dayi Bright Village	Zhangjiagang River	Suzhou→ Wangyu River	Suzhou→ Province	Ⅳ	4.18	0%	1.61	50%	0.19	0%	original
26	North Wangzhuang Bridge	Xibei Canal	Wuxi→ Suzhou	Wuxi→ Suzhou	Ⅲ	4.08	0%	1.42	92%	0.15	8%	original
27	Guan Pond	Xibei Canal	Suzhou→ Wangyu River	Suzhou→ Province	Ⅲ	3.33	0%	1.03	58%	0.16	0%	original
28	Xiajia Pond	Yangjian Pond	Wuxi→ Wangyu River	Wuxi→ Province	Ⅲ	4.38	0%	0.82	42%	0.19	25%	adjusted
29	Diaozhu Bridge	Jiuli Bridge	Wuxi→ Wangyu River	Wuxi→ Province	Ⅲ	3.65	0%	1	42%	0.13	0%	adjusted
30	Chengzekan Bridge	Bodu Harbour	Wuxi→ Wangyu River	Wuxi→ Province	Ⅲ	4.67	8%	1.22	50%	0.13	8%	original
31	Weidong Bridge	Li Harbour	Wuxi→ Yangtze River	Wuxi→ Province	Ⅲ	4.93	8%	1	25%	0.19	8%	increased
32	Nine Bridge	Zaojiang Bridge	Changzhou→ Yangtze River	Changzhou→ Province	Ⅳ	4.21	0%	0.78	8%	0.18	8%	increased
33	Liuhe Gate	Liuhe Pond	Suzhou→ Yangtze River	Suzhou→ Province	Ⅲ	3.08	0%	0.63	0%	0.13	0%	increased
34	Linjia Gate	Jiuqu River	Zhenjiang→ Yangtze River	Zhenjiang→ Province	Ⅲ	2.37	0%	0.3	0%	0.08	0%	increased

However, it has proven difficult to operate the scheme because of the controversy surrounding large pollutant fluxes. Therefore, in the method used in this study, thethe payment was calculated through the rate of water quality exceedances multiplied by compensation criterion. This method avoids the error caused by the differences in pollutant fluxes, which have raised the compensation criterion. It also takes the situations of reciprocating flow and water quality being up to standard into account.

Compensation types and pattern. There were four situations that applied to each compensation site (**Table 2**).

Payment calculation. For positive compensation (Situations No. 1 and 2), the payment was calculated using the following formula:

$$M_i = d \times (P_{COD} \times B + P_{NH_4^+-N} \times B + P_{TP} \times B) \quad (1)$$

$$M_k = \frac{\sum_{i=1}^{n} M_i}{n} \quad (2)$$

$$M_p = \sum_{k=1}^{12} M_k \quad (3)$$

where M_P is the annual punitive compensation payment, M_K is the monthly payment, and M_i is the payment based a single monitoring event; n is the number of monitoring events undertaken in a month; P_{COD}、P_{NH4+-N}、P_{TP} is the number of COD, NH_4^+-N, and TP exceedances, respectively, which equals 0 when the level does not exceed the standard; d is the directional regulation coefficient, *d= 1* for normal flow, *d = -1* for backward flow, and *d = 0* when the flow is stagnant; B is the punitive compensation criterion, which is proposed to be 0.25, 0.5, and 1 million CNY (0.036, 0.072, and 0.144 million USD), respectively, when the water quality exceeds the standard 0.5 (including 0.5), 0.5~1, and more than once, respectively. *B* is obtained by referring to the compensation standard implemented in the Tongyu River Basin of Jiangsu Province in 2010. The Taihu pilot region is located at the southern end of the Yangtze River, while the Tongyu River Basin is located at the northern end of the Yangtze River. The two research areas share the same geographical features and are typical multi-district river network areas.

For compensation sites that flow directly into the sea, Taihu Lake, Yangtze River, or out of Jiangsu Province stagnant flow could occur due to the operation of dam gates or other reasons. If the water quality exceeded the standard, then the upstream city would financially compensate the province, with a 70% payment discount calculated based on the value under normal flow conditions. There was no punitive payment for backward flow.

For reverse compensation (Situations No. 3 and 4), considering the economic development of Jiangsu Province, the criterion was 200,000 CNY (28,934 USD) per month. The payment was calculated using the following formula:

$$M_r = 20 \text{ x } m \quad (4)$$

where M_r is the annual reverse compensation payment; m is the number of months in the whole year in which the water quality of the compensation site met the standard.

The total payment for one compensation site was calculated according to flow as follows:

$$M = M_P + M_r \quad (5)$$

Pollutant treatment cost method (PTC method)

Although the WQER method is convenient and easy to operate, the water flow volume is ignored. This will result in lower payments for rivers with a large pollution flux but low pollutant concentrations. In addition, the determination of compensation criterion draws on the experience at other watersheds, which lacks a scientific basis. With the ongoing economic development in China, the government is establishing more hydrological and water quality automatic monitoring stations. Once this network is completed, the determination of pollution fluxes will not be as controversial as it currently is. Until then, a more scientific approach needs to be adopted. Therefore, a new method, based on a compensation criterion model that includes the treatment costs of sewage was proposed in this study.

Compensation types and pattern

The economic value of the natural environment is an important theoretical basis for the determination of eco-

Table 2. Four compensation situations for each site in the WQER method.

Situation No.	River Flow Direction	Water Quality Exceeding Standard	Compensation Direction	Compensation Type	Remarks
1	Normal flow	Yes	Upstream compensation downstream	Positive compensation	Punitive
2	Backward flow	Yes	Downstream compensation upstream	Positive compensation	Punitive
3	Normal flow	No	Downstream compensation upstream	Reverse compensation	Reward
4	Backward flow	No	Upstream compensation downstream	Reverse compensation	Reward

Remarks: whenever one of the COD, NH_4^+-N, or TP exceeded the standard, the water quality of the compensation site was considered to exceed the standard.

compensation criterion. The new compensation method takes the ecological service function of water pollution purification as its core value, and then attempts to estimate the amount of compensation due from the perspective of a cost compensation. The amount of compensation is calculated by multiplying an excessive pollutant flux by a compensation criterion. Here, the compensation criterion is defined as the treatment cost of each pollutant in a wastewater treatment plant. The compensation criterion model has been improved by being aligned with the Chinese Equal Standard Pollution Load (ESPL). The ESPL method is an assessment method used to evaluate the total impact of an industrial pollution source on the urban surface water environment and can be used to combine and compare different pollution impacts.

Payment calculation

The PTC method, taking a prefecture-level city as the unit, is used to calculate the excess pollution flux of all eco-compensation sites. The compensation criterion is mainly determined by the amount of pollutants removed annually and the annual operating cost of sewage treatment plants in each administrative region, which is based on pollution source survey data (provided free of charge by environmental authorities and accessed online). The calculation distributes the annual operating cost of the sewage treatment plant according to the Equal Standard Pollution Load Ratio (ESPLR) of each pollutant, and then divides by the annual amount of the corresponding pollution factor. The formulas used were as follows:

$$M = W_{COD} \times \gamma_{COD} + W_{NH_4^+-N} \times \gamma_{NH_4^+-N} + W_{TP} \times \gamma_{TP} \quad (1)$$

$$W_{COD} = \sum_{i=1}^{n} (C_i - C_S) \times Q_i \quad (2)$$

$$\gamma_{COD} = \frac{N \times K_{COD}}{R_{COD}} \quad (3)$$

$$K_{COD} = \frac{L_{COD}}{L_{COD} + L_{NH_4^+-N} + L_{TP}} \quad (4)$$

$$L_{COD} = \frac{10 \times R_{COD}}{C_A} \quad (5)$$

where M is the annual eco-compensation payment; W_{COD},$W_{\text{NH4+-N}}$,W_{TP} are the excess pollutant fluxes; Υ_{COD}, $\Upsilon_{\text{NH4+-N}}$, Υ_{TP} are the compensation criterion; C_i and Q_i are the pollutant concentration and river flow volume of a single measurement, respectively; C_s is the target water quality of a specific pollutant; n is the number of monitoring events; N is the annual operating cost of a sewage treatment plant; R_{COD} is the annual amount of COD removed; L_{COD} and K_{COD} are the ESPL and ESPLR values of COD respectively; C_A is the maximum allowable discharge concentration for "Class 1A" in the "Discharge Standard of Pollutions for a Municipal Wastewater Treatment Plant in China (GB18918-2002)", which is applied as a Chinese national standard. Formulas 7–10 use COD as a case study, but the same calculations can be applied for NH_4^+–N and TP.

RESULTS AND DISCUSSION

Eco-compensation payment

Payment based on the WQER method. The punitive payment for each compensation site was calculated using formulas 1–3, while the reward payment was calculated using formula 4. Then, the total compensation payment for each city was determined according to the relationships between the upstream and downstream cities connected by each compensation site.

The total financial expenditure in the Taihu pilot region used for eco-compensation was calculated by the WQER method was 172.4 million CNY (24.9 million USD), which was much higher than the 26 million CNY (3.76 million USD) that was actually paid (**Table 3**). Except for Suzhou, the calculated eco-compensation expenditures for the other prefecture-level cities were all higher than 10 million CNY (1.45 million USD), with the expenditure in Nanjing alone being 65.7 million CNY (9.5 million USD), while Wuxi's expenditure amounted to 36.3 million CNY (5.25 million USD). To some extent, the financial expenditure of each city required to pay the eco-compensation reflected the current water quality status. Linking the improvement of river water quality with economic activity could incentivize municipal government to conduct eco-compensation for water environment resources in watersheds. The total revenue of the province is almost 80 million CNY (11.57 million USD), which suggests the provincial government could invest more money in water management, water quality monitoring, and water source protection. Clearly, the use of the WQER method could guarantee the smooth implementation of eco-compensation in the river basin and gradually improve the quality of the regional water environment.

Payment based on the PTC method. The survey data collected from provincial industrial pollution sources included the amounts of COD, NH_4^+-N, and TP removed, as well as the annual operating cost of each sewage plant. These data are provided free of charge by

Table 3. Compensation payment for each city based on the WQER method.

City	Positive Compensation Payment (10 000 CNY)	Positive Accepted Compensation Payment (10 000 CNY)	Reverse Compensation Payment (10 000 CNY)	Reverse Accepted Compensation Payment (10 000 CNY)	Total Expenditure (10 000 CNY)	Total Revenue (10 000 CNY)
Nanjing	6 574	0	0	520	6 574	520
Wuxi	2 994	2 459	640	1 140	3 634	3 599
Changzhou	2 507	2 913	360	760	2 867	3 673
Suzhou	295	424	340	560	635	984
Zhenjiang	1 412	0	0	480	1 412	480
Provincial Finance	0	7 986	2 120	0	2 120	7 986
Total	13 782	13 782	3 460	3 460	17 242	17 242

The exchange rate of USD to CNY is 6.91 (10 000 CNY≈ 1 447 USD)

environmental authorities and can be accessed online. The total compensation payment and compensation criterion for each city based on the PTC method were calculated from formulas 6–10 (**Table 4**).

The calculated compensation payment based on the PTC method was 81.8 million CNY (11.8 million USD) in Nanjing, 67.4 million CNY (9.8 million USD) in Changzhou, and 56.4 million CNY (8.2 million USD) in Wuxi (**Table 4**). The other two cities had slightly lower compensation payments of about 20 million CNY (2.9 million USD). Because Nanjing is located in the upper Taihu Lake Basin area, there are many outgoing rivers and their water quality is relatively poor; therefore, the compensation payment in Nanjing was slightly higher. The water quality of the rivers in Changzhou and Wuxi was also poor, resulting in the next highest compensation payments after that of Nanjing. This also reflects the fact that the compensation payment can indicate the current water quality of each city to a certain extent.

Compensation criterion

In this study, different compensation criteria were adopted in the two water environment eco-compensation methods. In the WQER method, the punitive compensation criterion was graded based on thedifferent water pollutant concentrations, which was same approach as in the method used in Tongyu River Basin. Because the two research areas are both located at the end of the Yangtze River and share the same geographical features and are both part of a typical multi-district river network. The differences in economic activity and development pattern of the two regions are not large. Because they are located in the same province, the government will co-ordinate the use of environmental funds between them. The reverse compensation criterion was determined according to the current economic development and financial situation of Jiangsu Province. In 2013, the total GDP of the Taihu pilot region was about 3.64 trillion CNY (0.53 trillion USD). The total investment in environmental protection was about 100 billion CNY (14.47 billion USD). The overall expenditure on eco-compensation for the water environment accounted for only 0.17% of the total investment in environmental protection. Although total payments have increased nearly sevenfold compared to when the scheme was implemented (From 26 million to 172 million CNY) (3.76 million to 24.9 million USD), the overall investment is still quite low. The punitive and reverse compensation criterions were both empirical values and lacked a sufficient scientific basis, with both values subject to an appropriate increase in the course of the implementation.

The compensation criterion used in the PTC method was an improvement on the criterion used in the WQER method because it was based on the ESPL. It was

Table 4. Compensation payment and compensation criterion for each city based on the PTC method.

City	γCOD (10 000 CNY per ton)	γNH_4^+-N (10 000 CNY per ton)	γTP (10 000 CNY per ton)	Payment (10 000 CNY)
Nanjing	0.22	2.24	19.39	8 179
Wuxi	0.51	4.93	21.73	5 635
Changzhou	0.35	3.50	23.93	6 742
Suzhou	0.28	2.82	20.35	2 229
Zhenjiang	0.19	1.86	11.57	1 673
Average value	0.31	3.07	19.39	—

mainly determined by the amount of pollutants removed annually and the annual operating cost of a sewage treatment plant. The annual operating cost of a wastewater treatment plant was determined for each pollutant according to the ESPLR, and was then divided by the annual discharge of the corresponding pollutant. In this study, the average compensation criterion for COD, NH_4^+–N, and TP were set to 3,100, 31,000, and 194,000 CNY (448, 4,485, and 28,066 USD) per ton, respectively. According to the estimation, the overall expenditure on eco-compensation for the water environment accounted for 0.25% of the total investment in environmental protection, which was 1.5 times greater than the result calculated by the WQER method. These compensation criterion values were more realistic and had a scientific basis. The expenditure was within the appropriate range of investment, and therefore had both economic applicability and operational feasibility.

Effectiveness of the methods

Eco-compensation as an economic means to promote local environmental protection, links environmental pollution with economic compensation, therefore it further strengthens the environmental protection responsibilities of local governments, improves pollution control initiatives, and will lead to the achievement of water quality goals. If the eco-compensation payment required from the municipal financial expenditure of each city is higher than the range its current development can bear local government will be unwilling to undertake eco-compensation. Under such circumstances, local governments could default on compensation fees and shirk their river basin management responsibilities. On the other hand, if the eco-compensation payment is determined to be low, it could lead to local governments ignoring the water pollution problem and failing to improve the water environment overall. Therefore, the formulation of eco-compensation methods and standards should not only consider their operational feasibility, but also the achievement of suitable economic conditions.

The WQER method relies only on river water pollutant concentrations, which are available from government departments. Data provided from field monitoring can also be recorded over time to ensure the rapid and efficient implementation of an eco-compensation scheme. Because this method takes into account the situation of reciprocating flow, it avoids the embarrassing situation of "who affects who". The increase in the punitive payment and the implementation of incentive fees will help increase the government's motivation toward pollution control. The total expenditure for each city was deemed to be affordable for local governments. Large differences in expenditure and uneven financial burdens could stimulate improvements in the balance between economic development and environmental conservation. However, it also generates certain problems, for example, focusing only on high water quality levels, while ignoring river channels with a large pollution flux. This is not conducive to regional pollution reduction and the overall improvement of the water environment from an ecological perspective. Therefore, if this method is adopted, rivers with a large flow and relatively serious levels of water pollution should be comprehensively assessed when selecting compensation sites.

Compared with the WQER method, the PTC method takes into account the water quality, river discharge, and flow direction, and basically solves the problem of a "small compensation payment with large pollution flux". The payment for each city was slightly higher with the PTC method, but was also within the appropriate range of investment. The compensation criterion for each district was used to assess the local eco-compensation level. The PTC method has the advantage of being applicable anywhere as long as there is a national census of pollution sources, and therefore this method has practical value. Where no information is available, the compensation criterion for each water quality index considered could be used as a reference example. However, the calculation process is relatively complicated, with higher requirements for the simultaneous monitoring of water quality and river discharge. The PTC method is better than the WQER method from the environmental perspective and suitable for implementation in the near future.

Management

Whichever method is used, first, a special department should be established to ensure that the proposed payments for each district are spent wisely. Monitoring systems for water quality and hydrology should be mandatory in the eco-compensation areas. Second, compensation payments should be paid on time. Finally, the allocation of the payments should be strictly implemented. A fixed sum should be allocated for a fixed purpose. Compensation payments should be used to support environmental conservation in the upstream district, and more attention should be paid to polluted rivers.

CONCLUSIONS AND RECOMMENDATIONS

Due to the flawed formula and weak compensation criterion used in the "Environmental resources compensation scheme in the pilot region of Taihu watershed in Jiangsu Province (trial implementation)", which was initiated in 2007, the payments were considered unsuitable. The scheme encountered many problems during its implementation. Two potential solutions for evaluating regional water environment eco-compensation were considered in this study.

The WQER method was found to be convenient to use and highly operational. The data required were readily available and this ensured the rapid and efficient implementation of the scheme. The compensation criterion used was graded based on water quality. The calculated total financial expenditure in 2013 was 172.4 million CNY (24.9 million USD), which was almost seven times higher than for the original scheme, but was still affordable for local governments. However, this method tended to be unsuitable for rivers with low concentrations but high fluxes of pollutants, and therefore the density of monitoring sites in the region needs to be increased.

In the PTC method, a well-grounded compensation criterion that was improved by aligning with the ESPL was proposed. The average compensation criterion for COD, NH_4+–N, and TP was 3,100, 31,000, and 194,000 CNY (448, 4,485, and 28,066 USD) per ton, respectively. The slightly higher overall expenditure of 244.6 million CNY (35.4 million USD) was considered more appropriate, and more conducive to the environment. This method was also considered to be more practical because it can be applied anywhere as long as there is a national census of pollution sources. The premise is that the simultaneous monitoring of water quality and river flow is conducted. Due to the need to satisfy this premise and the complex calculation process, its implementation is proposed in the near future.

The government must invest funds into the construction of automatic hydrological and water quality monitoring stations in the region. It will then be necessary to increase the number of compensation sites in public water bodies, such as the Yangtze River and Yellow Sea, and to raise the level of rewards and punishments for destroying the environment of such locations. In addition, a relevant safeguard system should be established and improved, and a specific department should be established to coordinate and supervise the implementation of the eco-compensation scheme and use of the subsequent revenue. A successful eco-compensation policy could be a paradigm for balancing the relationship between rapid economic development and environmental conservation.

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