AQUA
Water Infrastructure, Ecosystems and Society

 AQUA — Water Infrastructure, Ecosystems and Society Vol 73 No 3, 662 doi: 10.2166/aqua.2024.016

Study on financial cost evaluation of urban water environment management and pollution prevention and control

Juan Jiang
Accounting College, Jiangsu Vocational College of Finance and Economics, Huai'an, Jiangsu 223003, China
E-mail: 19910512@jscj.edu.cn

ABSTRACT

Nowadays, water pollution has become a major factor restricting social development. To address this, the government has issued a series of policy documents to control water environmental pollution and achieved certain results. However, on the whole, the prevention and control of the pollution of water environments requires a large amount of capital investment, but the corresponding results and benefits are not significant. Hence, this paper takes Shanghai, Nanjing, Hangzhou, and Hefei as examples to study the financial cost-effectiveness of the governance of urban water environments from the two dimensions of time and space. It is concluded that the cost of water environmental treatment has a negative effect on the comprehensive benefit of environmental treatment in the region in the short term and a positive effect in the long term, which indicates that water environmental pollution treatment is work that needs to be adhered to for a long time, and long-term planning is also needed for cost input. On this basis, strategies to improve the cost efficiency of water pollution treatment are presented.

Key words: cost-effectiveness, cost input, evaluation, pollution prevention and control, water environment governance

HIGHLIGHTS

- There may be missing or unmeasurable control variables, which will lead to the random error term including the influencing factors of environmental benefit.
- The cost of the governance of water environments has a negative effect in the short term and a positive effect in the long term.
- It is also necessary to optimize the top-level design of water environmental pollution control in the lower Yangtze River Economic Belt.

1. INTRODUCTION

As the foundation of social development, the demand for water resources is constantly increasing, creating serious development problems in terms of water resources shortage, water resources destruction, and water environment pollution. This problem has also been highly concerning for government departments. Therefore, a series of systems have been introduced to urgently solve the problem of water environmental pollution. But from the realistic point of view, the traditional concept of water environment governance, through the construction of sewage treatment plants, huge capital investment, management ability, and treatment technology for the government, poses a huge challenge. A total of 240 billion yuan has been invested in 1,789 water environmental governance projects, according to the report 'From Quick Decisive Battle to Long-term Governance' released by the Alxa SEE Foundation and the Institute of Public and Environmental Affairs. It can be seen that one of the difficulties in the governance of water environments is the huge demand for funds, which brings a sharp increase in the financial pressure on local governments, and it is obvious that the financial resources are not enough to support water environmental pollution control projects.

To solve this problem, relevant experts and scholars have also started a series of studies. Based on the data of environmental pollution control in the Netherlands from 1990 to 2000, Dellink & van Ierland (2006) conducted a study on the government's environmental pollution control efficiency, and the results showed that to achieve the established pollution control targets in the Netherlands, the total amount of investment needed would be more than 11% of the annual GDP. Huixin & Xiaotong (2018) studied the investment efficiency of environmental pollution control in the Beijing–Tianjin–Hebei region, and the research results showed that the investment efficiency of environmental pollution control in the

Beijing–Tianjin–Hebei region showed a trend of continuous decline. Jing *et al.* (2019) constructed a Data Envelopment Analysis (DEA) model to calculate the air pollution investment benefit in the Beijing–Tianjin–Hebei region, and the research results show that the air pollution treatment efficiency in the region is characterized by large differences and diversification. Moreover, Zhu (2016) takes a township sewage treatment plant project as an example, identifies 32 key risk factors affecting social capital investment by using the combination method. Based on the standard of project investment return rate, Monte Carlo analysis is used to evaluate the impact of different indicators on the project investment return rate. Then compared with the benchmark rate of return of the industry, the risk factors were evaluated and the boundary control conditions of investment feasibility were obtained, which provided the negotiation basis for decision-makers.

Through the overall summary of the aforementioned literature, it can be seen that the study of environmental governance and its cost-effectiveness has become a hot topic today. Scholars have carried out a series of discussions on specific pollution types from different dimensions, and achieved certain research results (Fleming 2017; Kyei & Hassan 2019; Domingues *et al.* 2022; Imane *et al.* 2023; Junfeng *et al.* 2023; Singh & Roushan 2023).

In the context of financial cost evaluation of urban water environment management and pollution prevention and control, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) can play several major roles (Czyżewski *et al.* 2020; Juan *et al.* 2023; Ningjing *et al.* 2023; Wendong *et al.* 2023; Yu *et al.* 2023; Yuting *et al.* 2023). This model identifies and defines the criteria that are relevant to the financial cost evaluation of urban water environment management and pollution prevention and control. These criteria may include capital costs, operational costs, maintenance costs, and other financial parameters. Additionally, weights are assigned to each criterion based on their relative importance in the decision-making process. For example, if minimizing costs is a primary concern, financial criteria may be assigned higher weights (Susan *et al.* 2020; Po *et al.* 2022; Jinzhao *et al.* 2023; Wu *et al.* 2023). The criteria are normalized to ensure that they are on a similar scale. This is crucial when dealing with different units or magnitudes of measurement for various criteria. The next stage is to determine the ideal and anti-ideal solutions for each criterion. The ideal solution represents the best possible value for each criterion, while the anti-ideal solution represents the worst. These values serve as reference points for evaluating the alternatives (Noda 2018; Hilbig & Rudolph 2019). Moreover, the similarity of each alternative to the ideal and anti-ideal solutions for all criteria is evaluated. TOPSIS calculates a similarity score for each alternative based on its distance to the ideal solution and proximity to the anti-ideal solution. In the stage of ranking and decision-making, the alternatives based on their similarity scores are ranked (Peng *et al.* 2023a). The alternative with the highest similarity score is considered the most preferable in terms of financial cost for urban water environment management and pollution prevention and control (Acosta-Vega *et al.* 2023; Po *et al.* 2022). Sensitivity analysis is carried out to assess the sensitivity of the results to changes in criteria weights. This helps in understanding how variations in the importance of criteria impact the final decision. Furthermore, decision-makers are provided with a clear and systematic method for evaluating and comparing different alternatives for urban water environment management. This facilitates informed decision-making based on financial considerations.

On the whole, most studies on the cost of environmental governance are evaluated and measured from the perspective of environmental problems and environmental pollution products, and the evaluation index of environmental governance cost–benefit is established. However, most studies are carried out by combining ecological benefits, social benefits, and economic benefits, and few studies are carried out solely on the financial cost–benefit of water environmental governance (Li *et al.* 2023; Meghea 2023; Peng *et al.* 2023b). Hence, this paper takes four specific cities as examples to study the financial cost assessment of their water environment governance. The key contributions of this paper are as follows:

(1) The total cost input for urban pollution control in the four cities from 2010 to 2020 is analyzed, and then the time distribution of the cost–benefit of water pollution control in the four cities is analyzed by taking sewage discharge as an example.
(2) The cost evaluation model of water pollution treatment was established by using the entropy method and the TOPSIS model. In total, 155 data samples were selected, and the explained variables, explanatory variables, and control variables were determined. Descriptive statistics were carried out on the data.
(3) Based on the spatial dimension, the Strategic Data Management (SDM) spatial metrology model is built, and Stata 15.0 software is used to evaluate the model. The data are analyzed, and the corresponding research conclusions are drawn.

This paper mainly studies the cost-effectiveness of water environmental governance from the two dimensions of time and space. In terms of time dimension, this paper first analyzed the time distribution of the cost and benefit of water environment governance in four cities, then built a cost evaluation model, analyzed the panel data of the four cities from 2015 to 2020 and drew corresponding conclusions. In the spatial dimension, first, the spatial correlation is tested, the impact model of environmental governance cost on environmental benefit is built, and the corresponding conclusions are drawn through data analysis. Finally, the results of all the research are summarized, and the optimization suggestions are given. The research process of this paper is shown in Figure 1.

2. ANALYSIS OF COST–BENEFIT TIME DISTRIBUTION FOR WATER ENVIRONMENTAL GOVERNANCE

2.1. Total investment in environmental pollution control

For environmental governance, the most effective and direct way is pollution control investment, which is a kind of financial investment that reflects the importance of the role played by the government and even the whole society in environmental pollution control. In this paper, four cities in the Yangtze River basin, namely, Shanghai (SH), Nanjing (NJ), Hangzhou (HZ), and Hefei (HF), were selected to study the cost of water environmental governance. The total investment in pollution control in the four cities from 2010 to 2020 is shown in Figure 2.

As can be seen from the figure, the total investment in environmental governance in the four cities over the years follows a gradual upward trend and is increasing year by year. However, due to the differences in regional industrial structure, economic growth level, environmental pollution intensity, and environmental governance capacity, there are differences in environmental governance investment among the cities. For example, Nanjing has the highest investment in environmental pollution control, while Shanghai's total investment is relatively small and remains stable.

2.2. Analysis of cost–benefit time distribution of water environment governance

The lower reaches of the Yangtze River are rich in water resources owing to its unique topography, abundant resources, abundant tributaries, dense river network, and numerous lakes. But at the same time, the four cities in the lower reaches of the Yangtze River have a large population, a developed economy, and large water consumption, and the sewage discharge cannot be underestimated. On the whole, from 2010 to 2020, sewage discharge in the four cities was on the rise, and the situation of water pollution was not optimistic. Secondly, from the point of view of each city's discharge, Nanjing and Hangzhou's wastewater discharge was outstanding, nearly twice that of Hefei. The reason is that Nanjing and Hangzhou are located in the Yangtze River Delta, with rapid industrialization and urbanization and a high concentration of polluting industries. In addition, in the suburbs and the vast rural areas, there are more large-scale and small-scale aquaculture systems,

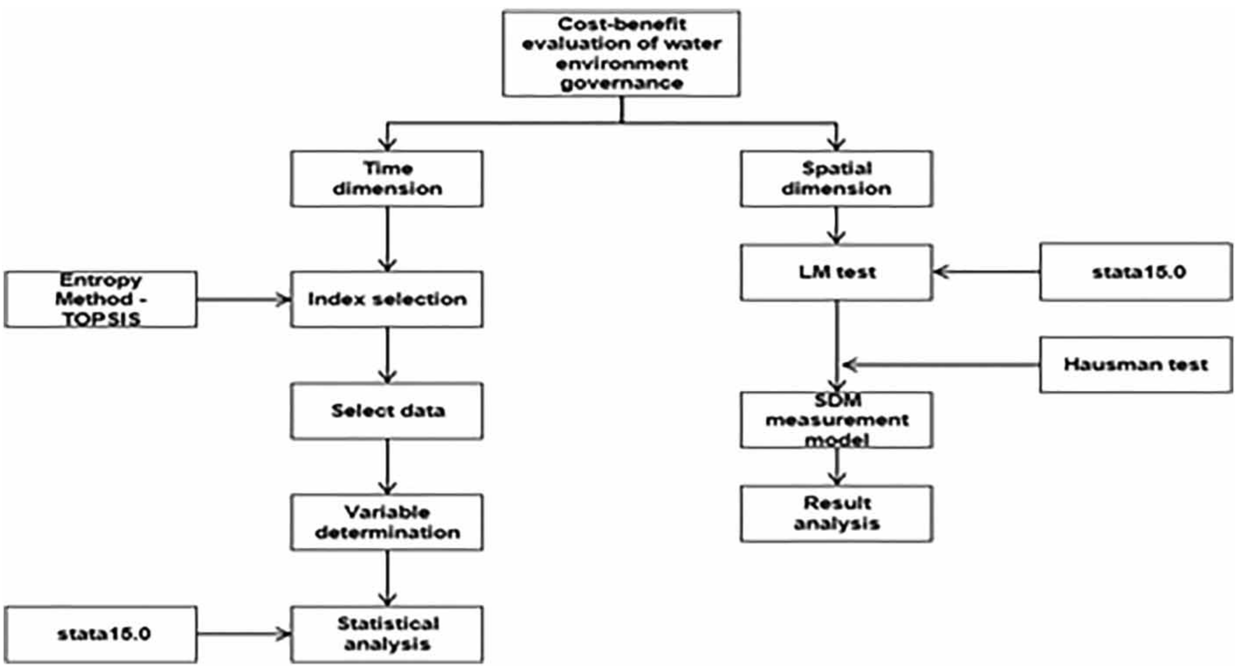

Figure 1 | Research process.

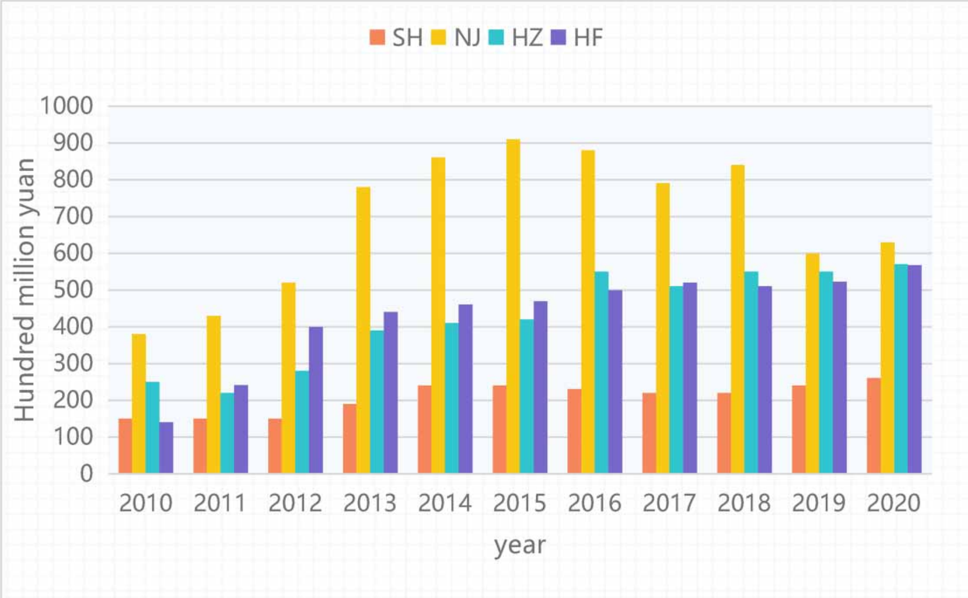

Figure 2 | Changes in total investment in pollution control in the lower Yangtze River Economic Belt.

resulting in non-point source pollution and a large amount of wastewater discharge pollution. The time distribution of total sewage discharge in the four cities is shown in Figure 3.

In terms of water pollution, the chemical oxygen demand and ammonia nitrogen discharge showed a trend of increasing first and then decreasing, with 2011 as the turning point. Since 2011, the four cities have adopted scientific measures to reduce emissions and environmental protection, resulting in significant reductions in water pollutants. From 2010 to 2020, chemical oxygen content was reduced by about 40%, ammonia nitrogen by about 30% and water pollution was significantly controlled. In short, in terms of water environmental pollution in the lower Yangtze River Economic Belt, Hangzhou has paid more attention to water protection and has achieved a large reduction in chemical emissions. The specific emission reduction percentage and ranking are provided in Table 1.

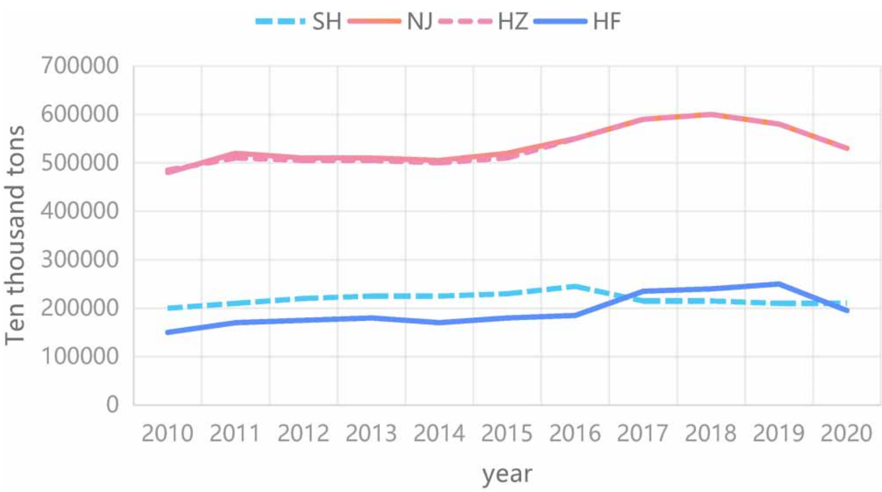

Figure 3 | Time distribution of total sewage discharge in four cities.

Table 1 | Ranking of water pollution emission reduction in the four provinces and cities in the lower reaches of the Yangtze River

	Chemical oxygen demand		Ammonia nitrogen compounds	
Regions	Reduction	Rankings	Magnitude of reduction	Rankings
Shanghai (SH)	−51.60%	2	−29.37%	4
Nanjing (NJ)	−45.07%	4	−38.87%	3
Hangzhou (HZ)	−54.08%	1	−47.66%	1
Hefei (HF)	−48.09%	3	−46.36%	2

3. CONSTRUCT COST EVALUATION MODEL

3.1. Index selection

The selection of benefit indicators of water environmental governance needs comprehensive consideration. The total investment in water environmental pollution control is selected as an independent variable in this paper, and the benefit indicators of water environmental governance mainly include environmental benefits, economic benefits, and social benefits. Improved water quality environmental benefit is the most direct output of water environmental governance, which is mainly reflected in the discharge and utilization of various water environmental pollutions. In this paper, the total amount of industrial wastewater discharge is selected to measure environmental benefits of water governance. Considering the comprehensive benefits of water environment treatment, it is concluded that while some output variables of water environment treatment are positive indicators, such as urban sewage treatment rate, some are negative indicators, such as total industrial wastewater discharge.

In this paper, the entropy method–TOPSIS– is used to determine the weight, and comprehensive evaluation value is obtained. The specific calculation steps are as follows:

(1) Determine the index weight

$$\text{Positive indicators: } X'_{ti,j} = \frac{X_{ti,j} - \min\{X_j\}}{\max\{X_j\} - \min\{X_j\}} \quad (t = 1, 2 \ldots, 11;\ i = 1, 2, 3, 4;\ j = 1, 2) \tag{1}$$

$$\text{Negative indicators: } X'_{ti,j} = \frac{\max\{X_j\} - X_{ti,j}}{\max\{X_j\} - \min\{X_j\}} \quad (t = 1, 2 \ldots, 11;\ i = 1, 2, 3, 4;\ j = 1, 2) \tag{2}$$

$$\text{Amount of adjustment: } X'^{+}_{ti,j} = X'_{ti,j} + 0.001 \tag{3}$$

where t is the year; i is the number of each city: 1 stands for SH, 2 stands for NJ, 3 stands for HZ, and 4 stands for HF; j is the indicator: 1 represents the positive indicator and 2 represents the negative indicator.

(2) Calculate the weight range normalization matrix $\{S_{it}, j\}_{154\times 26}$
(3) Determine positive ideal solution sets and negative ideal solution sets.

The set of positive ideal solution sets:

$$\{S_j^+\} = \{\max\{S_{ti,1}\}, \max\{S_{ti,2}\}$$

The set of negative ideal solution sets:

$$\{S_j^-\} = \{\min\{S_{ti,1}\},\ \min\{S_{ti,2}\}$$

(4) Compute the Euclidean distance and negative Euclidean distance of the ith city in year t from the positive ideal set.

$$d_{it}^{+} = \sqrt{\sum_{j=1}^{2} (S_{ti,j} - S_j^{+})^2} \tag{4}$$

$$d_{it}^{-} = \sqrt{\sum_{j=1}^{2} (S_{ti,j} - S_j^{-})^2} \tag{5}$$

(5) Calculate the ith city in year t by using the negative ideal solution set as the basis through the measure and the negative ideal set distance to measure the degree of proximity to the positive ideal indirectly.

$$\lambda_{ti} = d_{ti}^{+}/(d_{ti}^{+} + d_{ti}^{-}), \quad \lambda_{ti} \in [0, 1] \tag{6}$$

In the formula, the larger the valueλ_{ti}, the closer it is to the positive ideal solution set of the decision goal, that is, the higher the comprehensive benefit level of environmental governance.

(6) The time model of cost-effectiveness is:

$$C(t) = Fc(t) + Vc(t) \tag{7}$$

In the formula, $C(t)$ is the total cost, $Fc(t)$ is the fixed cost, and $Vc(t)$ is the variable cost.

According to the above steps, the comprehensive index value of the four cities' water environment governance benefits is shown in Figure 4.

Based on the aforementioned data, it can be seen that the economic development of Shanghai is fast, and the comprehensive benefits of environmental governance are the highest, while the water environment governance indicators of Nanjing and Hangzhou are also at a higher level; however, the development of water environment quality indicators of Hefei has been faster in recent years.

3.2. Sources of data

To carry out an objective and comprehensive assessment of the cost of water environmental governance, it is also necessary to conduct an in-depth analysis of the comprehensive benefits of water environmental governance, including the contents from various aspects such as environment and economy. Based on this, the panel data of Environmental Statistical Yearbook and Regional Statistical Yearbook of the four cities from 2015 to 2020 were selected as the data source. After collecting the original data, the data analysis was not carried out immediately, but instead meticulous screening and cleaning were carried

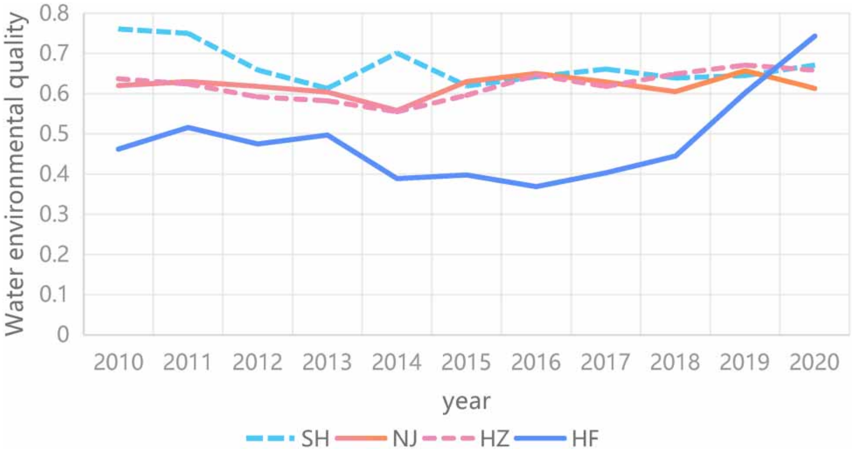

Figure 4 | Comprehensive index of water quality in four cities from 2010 to 2020.

out. This is mainly because the raw data may contain some obvious errors or outliers that, if not processed, may adversely affect the analysis results. To ensure the accuracy and reliability of the data, each item of data was carefully examined first. Data that were clearly illogical or contrary to reality were eliminated. For example, if there were unusually high or low values for certain indicators in certain years that were significantly inconsistent with the city's historical data or other relevant data, we treated them as outliers and excluded them, ultimately identifying 155 sample data for analysis.

3.3. Selection of variables

This paper mainly involves three variables: explanatory variable, explained variables, and control variables. The explanatory variable is the cost of water environment management. The explained variables are the benefits of water environment management, including ecological, economical, and social benefits. The control variables were determined by studying the influencing factors of environmental governance benefits at home and abroad. The value methods, specific meanings, and representative symbols of relevant variables are provided in Table 2.

(1) Upgrading of industrial structure

Industry, as the secondary industry, is an important source of sewage, which seriously damages the ecological environment. In the context of urban water environment governance, reducing the proportion of the secondary industry can improve the efficiency of water environment governance. Therefore, this paper selects the upgrading of industrial structure (IU) as the control variable. The formula for calculating IU is as follows:

$$\mathrm{IU} = \frac{\text{Value added in tertiary industry}}{\text{Value added in secondary industry}}.$$

(2) Environmental regulation

The intensity of water environment regulation is the expression of local governments' attention to the environment. Regulation of water environments can effectively stimulate the development of low-energy and low-pollution industries and effectively promote the environmental benefits of water governance. In this paper, the ratio of the total investment in water environment management to the industrial output value of the region is chosen to be measured. The calculation formula of environmental regulation (ER) is as follows:

$$\mathrm{ER} = \frac{\text{Pollution control investment amount}}{\text{Regional industrial added value}}.$$

(3) Technological progress

The scale and intensity of R&D investment are often used to measure the scientific and technological innovation ability of a region. In this paper, the proportion of R&D investment and GDP are chosen to measure the scientific and technological innovation of each city.

Table 2 | Variable meaning and symbol description

Variable names	Symbol		Variable description
Explained variable	Comprehensive benefits of water environmental governance	EB	Efficiency coefficient of water environment treatment
Explanatory variables	Water environmental governance costs	EC	Total investment in water environmental pollution control
Control variables	Upgrading of industrial structure	IU	Industrial structure upgrading coefficient
	Regulation of water environments regulation	ER	Environmental regulation intensity
	Technological progress	TI	R&D expenditure as a share of GDP

3.4. Descriptive statistics of variables

In this paper, Stata 15.0 is used to process the data and obtain the basic characteristic values of the variables, as shown in Table 3.

It can be seen from the data in the table that the minimum value, maximum value, and standard deviation of environmental governance benefits of the explained variables are 0.2836, 0.7882, and 0.1208, which indicates that the systematic difference of water environment governance benefits of the four cities in the lower reaches of the Yangtze River is not very large. However, since the relative value of the environmental benefits of water governance is obtained using the entropy method, even small differences make different cities in the lower Yangtze River Economic Belt show different characteristics of environmental benefits of water governance.

4. SPATIAL DISTRIBUTION ANALYSIS OF COST–BENEFIT OF WATER ENVIRONMENT GOVERNANCE

4.1. Spatial correlation test

Before the construction of the spatial metrology model, it is necessary to test whether there is a spatial correlation. In this paper, Stata 15.0 is used to select the spatial geographical weight matrix for Lagrange Multiplier (LM) test, as presented in Table 4. When the P value of Moran index is 0.0000, it means that the original hypothesis is not valid. It can be seen from the data in the table that there is a significant spatial correlation between the cost-effectiveness of water environmental governance.

4.2. Selecting a spatial metrology model

The main spatial metrological models are SDM, Spatial Error Model (SEM), and Spatial Autoregressive Model (SAR). To select a suitable model, Stata 15.0 and Hausman tests were used in this paper and then spatial fixed effects were selected to conduct Logistic Regression (LR) tests. The specific results are provided in Table 5. Consequently, we choose the SDM model.

4.3. Building the econometric model

The cost of water environment governance at the macro level can bring positive benefits to the social environment from all aspects. They interact and work together on the environment to promote ecological friendliness, green economic growth, and social environment optimization. Spatial autocorrelation analysis proves that the environmental benefits of water governance have strong spatial correlation and spatial structure, and the general panel data model can no longer accurately describe the relationship between variables. Therefore, in this paper, combined with the aforementioned test results, the Hausman test is

Table 3 | Descriptive statistics of variables

Names of variables	Mean	Standard deviation	Minimum	Maximum	Sample size
EB	0.5133	0.1208	0.2386	0.7882	155
EC	220.0419	187.1973	14.1	952.5	155
IU	0.9877	0.3118	0.5984	2.4656	155
ER	0.0043	0.0051	0.0006	0.03	155
TI	14.0247	1.3325	10.6892	16.8234	155

Table 4 | LM inspection results

Null hypothesis	Test method	Statistics	*P*-values
No spatial error	Moran's I	311.136	0.000
	LM error	28.275	0.000
No spatial lag	Robust-LM error	14.254	0.000
	LM lag	16.531	0.000
	Robust-LM lag	2.511	0.113

Table 5 | LR inspection results

	SDM	SAR	SEM
Sigma^2	0.000*** (8.77)	0.000*** (8.77)	0.000*** (8.77)
R^2	0.6663	0.3826	0.3903
Log-likelihood	231.7631	208.4218	208.5016
ρ	0.879 (0.15)	0.966 (0.04)	–

*, **, and *** are significant at the test level of 10, 5, and 1%, respectively. The $t(Z)$ statistic is in parentheses.

used to determine whether to use the random effects method or the fixed effects method, and environmental benefits are taken as the dependent variable, to construct a bidirectional fixed-effect SDM model on the impact of environmental governance costs on environmental benefits, as follows:

$$\mathrm{EB}_{it} = \rho \times W\mathrm{EB}_{it} + \alpha_1 \mathrm{EC}_{it} + \alpha_2 \mathrm{Control} + \theta_1 W\mathrm{EC}_{it} + \theta_2 W\mathrm{Control} + \delta_i + \mu_t + \varepsilon_{it} \tag{8}$$

In the formula, EB is the comprehensive benefit of water environmental governance, EC is the cost of water environmental governance, and Control represents various control variables, including IU, ER, and Technical Indicators (TI). i is the city, t is the year, δ_i is the spatial trait effect, μ_t is the period trait effect, and W is the spatial weight matrix.

Considering that the effect of water environment governance investment on the environmental benefits from water governance cannot be achieved overnight, this is a slow transformation process. Moreover, the model may have endogenous problems. On the one hand, the cost of water environmental governance has an impact on the environmental benefit, and the environmental benefit affects the social green ecology, economy, and life, and then affects the government's investment in water environmental governance. On the other hand, there may be missing or unmeasurable control variables, which will lead to the random error term including the influencing factors of environmental benefit. Therefore, the lag term of industrial structure upgrading (EB_{it-1}) is added to the model to form a dynamic spatial panel data model.

The dynamic spatial panel data model is a statistical model used to analyze the dynamic changes in space and time. It combines the theories and methods of spatial econometrics and dynamic panel data, considering the interaction of spatial and temporal effects. In the dynamic spatial panel data model, there are usually two main components: spatial weight matrix and dynamic lag term. Among them, the lag item (EB_{it-1}) refers to the previous period of industrial structure upgrading data. The lag term is mainly used in time series analysis. When the change of an economic indicator takes a certain time to reflect, the lag term of this indicator can reflect this time delay effect. In the study of industrial structure upgrading, the lag term (EB_{it-1}) represents the degree of industrial structure upgrading in the previous period. In other words, when we consider the upgrading of the industrial structure in the current period, we need to consider the upgrading of the industrial structure in the previous period, because the upgrading of the industrial structure may take a certain amount of time to complete. The introduction of the lag term can help us better understand the dynamic changes of economic phenomena. The dynamic spatial panel data model is widely used to analyze the spatial and temporal dynamics of regional economic growth, industrial agglomeration, and population migration. Through this model, we can better understand the spatial correlation and time trend of economic phenomena, and provide a scientific basis for policymaking.

$$\mathrm{EB}_{it} = \tau \mathrm{EB}_{i,t-1} + \rho \mathrm{WEB}_{it} + \beta_1 \mathrm{EC}_{it} + \beta_2 \mathrm{control}_{it} + \delta_1 W\mathrm{EC}_{it} + \delta_2 W\mathrm{control}_{it} + \mu_i + \gamma_t + \varepsilon_{it} \tag{9}$$

where i is the city, t is the time, W is the spatial matrix, μ_i is the spatial fixed effect, γ_t is the time fixed effect, and ε_{it} is the error term.

4.4. Analysis of results

Stata 15.0 software was used to estimate the time–space dual fixed-effect model with the maximum likelihood estimation method. The specific results are provided in Table 6.

Through the analysis of the aforementioned data, it can be seen that the government's macro water environment governance cost cannot improve the comprehensive environmental governance benefits of the region in the short term, although it

Table 6 | Estimation results of the spatial Dubin model

	Model		Models
EB (t − 1)	0.4738*** (6.81)	W*EB (t − 1)	0.2273 (−1.23)
EC	0.0001 (−1.91)	W*EC	0.0004*** (−2.57)
IU	0.0398 (1.25)	W*IU	0.0266 (0.44)
ER	1.0858 (−0.83)	W*ER	1.7600 (1.10)
TI	0.0864** (2.42)	W*TI	0.0411 (−1.05)

*, **, and *** are significant at the test level of 10, 5, and 1%, respectively. The Z-statistic is in parentheses.

will bring positive environmental benefits to the region in the long run. Long-term environmental cost input is conducive to improving the comprehensive environmental benefit in the region. The benefit indicators of water environment governance selected in this paper include ecology, economy, and society. The results show that investment directed to industrial pollution governance in water environments will inhibit the economic growth of the region and produce negative benefits in the short term. However, in the long run, water environment governance will force the upgrading of industrial structure, increase green industry, and bring environmental benefits. In addition, the investment in water environment governance, infrastructure construction, and the establishment of environmental protection equipment will not have an immediate impact on the social output, with environmental benefits only manifesting after the passage of time.

Secondly, the cost of water environment governance has a significant negative spatial spillover effect on environmental benefits. In the long run, the impact of spatial environmental governance cost on other environmental governance benefits is still negative, but not significant. It indicates which environmental governance costs bring negative environmental fallouts to other areas. In the lower Yangtze River Economic Belt represented by Shanghai, Nanjing, Zhejiang, and Hefei, environmental benefits will show a continuous change. The impact of water environmental governance on environmental benefits in the region will have an impact on other cities. It will make the industries with high pollution and high energy consumption move to the regions with relatively backward economic development level and weak environmental awareness, resulting in negative spatial benefits of environmental governance.

Finally, the upgrading of industrial structure is the key obstacle for water environment governance costs to obtain environmental benefits in the short term, and technological progress is the key reason for the difference in water environment governance benefits between regions. Environmental regulation plays an important role in promoting environmental benefits in the short term. The upgrading of industrial structure is positive but not significant in the model. In the model, the impact of technological progress on environmental benefits is significantly negative, indicating that regional scientific and technological progress will accelerate the transfer of heavy industry to other regions. In the model, the impact of environmental regulation on the benefits to water environments in this region and other regions is significantly positive at 1%, but not significant in the long run. This indicates that the effect achieved by the government through a series of fiscal measures to control water pollution is only temporary and cannot maintain long-term effect. The realization of the water environmental cost-effectiveness of governance should be based on promoting technological innovation to achieve long-term ecological, economic, and social benefits.

5. CONCLUSIONS AND RECOMMENDATIONS

To sum up, against the background of advocating for the construction of an ecological society, water pollution control has become one of the key issues concerning people from all walks of life. Taking the key cities of Shanghai, Nanjing, Hangzhou, and Hefei in the lower Yangtze River Economic Belt as examples, this paper evaluates the cost and benefits of the governance of water environments from the two dimensions of time and space by using the econometric model. From the perspective of the dimension of time, the systematic difference in the water environment governance benefits of the four cities in the lower reaches of the Yangtze River is not very large. However, since the water environment governance benefits are relative numbers obtained by the entropy method, even small differences make different cities in the lower reaches of the Yangtze River Economic Belt show different characteristics of environmental benefits of water governance. From the perspective of spatial dimension, the government's macro water environment governance costs cannot improve the comprehensive environmental governance benefits of the region in the short term, but will bring positive environmental benefits to the region in the long term. The cost of water environment treatment has a significant negative spatial spillover effect on environmental benefits. It is concluded that the cost of the governance of water environments has a negative effect in the short term and a positive effect in the long term. The cost of water environmental governance has a significant negative spatial spillover effect on environmental benefits, and the realization of water environment cost–benefits needs to rely on high-tech development and industrial upgrading. Only in this way can the coordinated development of green ecology, economy, and society be realized.

In this regard, relevant departments should first further improve the rules and regulations of water environment governance in the lower Yangtze River Economic Belt, and adopt regional policies, coordinated governance, and differentiated water environment protection policies to guide the high-level governance of water environments in the lower Yangtze River basin. Secondly, it is also necessary to optimize the top-level design of water environmental pollution control in the lower Yangtze River Economic Belt, promote the coordinated management of the whole basin of the lower Yangtze River Economic Belt, integrate the fine management objectives into the water environment governance process, and comprehensively improve the benefits of water environment governance. Finally, the application of high and new technologies in water environment governance should be accelerated, and it should be transformed into practical application of environmental protection technology achievements, and the efficiency of converting water environment governance costs into ecological, economic, and social benefits should be improved.

DATA AVAILABILITY STATEMENT

Data cannot be made publicly available; readers should contact the corresponding author for details.

CONFLICT OF INTEREST

The authors declare there is no conflict.

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First received 8 January 2024; accepted in revised form 27 January 2024. Available online 9 February 2024