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Original Research

A holistic approach to evaluating environmental policy impact using a difference-in-differences model

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ABSTRACT

Environmental protection policies (EPPs) play a pivotal role in advancing sustainable development and maintaining ecological balance by establishing clear directives and standards. However, a comprehensive methodology to evaluate the effectiveness of these policies remains underdeveloped. Here, we employ a difference-in-differences (DID) approach to assess the effectiveness of EPPs, using the implementation of the Resident Work (RW) policy as a quasi-natural experiment. Drawing on urban-level panel data from the Yangtze River Basin between 2016 and 2021, we demonstrate that the DID model robustly evaluates the RW policy's impact on water quality improvement. Cities that adopted the RW policy experienced a 0.0098 reduction in water pollution compared to non-adopting cities. A dynamic analysis revealed progressive water quality improvements over time, with stronger effects observed in economically disadvantaged cities. Furthermore, higher policy evaluation scores correlated with greater improvements in water quality. This study highlights the utility of the DID model in quantifying EPP effectiveness and offers a scalable framework for policy evaluation in environmental management.

1. Introduction

Environmental protection policies (EPPs) have long been the focus of international attention. Reasonable EPPs are fundamental for environmental governance and often serve as the main means for resolving the contradiction between environmental protection and socioeconomic development [1]. For example, Aziz et al. [2] found that EPP implementation substantially reduced greenhouse gas emissions in Canada. Nie et al. [3] found that marine environmental protection law promotes scientific and technological innovation in coastal cities. Bonatti et al. [4] explored how best to promote the restoration and protection of biodiversity through the formulation of effective EPPs. They clarified the importance of successfully implementing such policies in biodiversity conservation.

As the largest developing country in the world, China has implemented a series of EPPs to provide a strong institutional guarantee for environmental protection. The Yangtze River, the third longest river in the world, supports more than 40% of China's population across less than 20% of the country's land area and contributes 35% to China's gross domestic product. To strengthen environmental protection in the Yangtze River Basin [5], China implemented the resident work (RW) policy in 2018. This involved organizing more than 5000 interdisciplinary scientists and researchers to settle in 58 cities in 12 provinces throughout the Yangtze River Basin to provide local governments with long-term environmental pollution control technical services and management advice, thereby helping to improve local water quality [6–8]. Under the support of the RW policy, the proportion of sections with high water quality (classes I–III) in the Yangtze River Basin increased from 87.5% in 2018 to 97.1% in 2021.

Many previous studies investigating the effect of EPP implementation focused on the ecological and economic benefits. For example, Yin and Yang [9] studied the effectiveness of

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implementing China's iron ore resource tax policy in improving the environment and increasing production efficiency. Yuan et al. [10] examined the effectiveness of environmental standards in reducing pollutant emissions in Shandong Province, China, and found that each implementation of new standards substantially reduced pollutant emissions. Wu [11] found that climate policy implementation positively impacts carbon emission reduction, economic development, technological innovation, and energy efficiency. However, Feng et al. [12] and Mao et al. [13] both found that the effectiveness of such policies is affected by many factors and that the influence of the social, economic, and cultural backgrounds should be fully considered. Current approaches are inadequate for dynamic evaluation of the impact of EPPs after their implementation, and an in-depth analysis of the heterogeneity of policy effects is worthwhile. Moreover, since the implementation of the RW policy, detailed studies have been conducted on its system and mechanism design, operation mode, organization design, and path planning [7,14], but empirical research on the effect of the RW policy on water quality improvement in the Yangtze River Basin remains lacking. Therefore, an accurate evaluation of the RW policy is important for undertaking current and future environmental protection work in the Yangtze River Basin.

The difference-in-differences (DID) model, which originated in the field of econometrics [15], is considered one of the three most important quasi-experimental research designs [16]. The DID approach is typically used to evaluate the effects of public interventions and other treatments of interest on specific relevant outcome variables, and it has been used widely to assess the effects of economic policies, health policies, and educational projects [17–19]. Given the advantages of the DID method in policy assessment and causal inference, some studies have applied the DID approach to the environmental field [20–25]. Earlier studies analyzed the impact of environment policies on regional or corporate economic efficiency, such as the export-domestic value-added ratio [26], green transformation, and innovation [27,28]. Moreover, other studies tried to measure the effect of EPPs on air or water quality [29–31]. However, there has been little consideration of the differences in treatment effects among different cities; consequently, the objective of this study was to attempt to explore the heterogeneity of policy effects.

This study conducted an empirical test of EPP effectiveness using the DID method, and it focused on the impact of the RW policy on water quality improvement in the Yangtze River Basin based on panel data from 2016 to 2021. It tried to distinguish whether cities that implemented the RW policy had greater improvement in water quality compared with those cities that did not adopt the RW policy. The main contributions of this study are as follows. First, previous studies elaborated on the RW policy mostly from the perspective of theoretical mechanisms and guarantees. In contrast, this study empirically verified the effectiveness of the RW policy in improving water quality in the Yangtze River Basin. Second, compared with direct consideration of the scale of the entire Yangtze River Basin, this study verified the function of the RW policy at the city scale and investigated the differences between cities with different levels of economic development. Moreover, the effectiveness and differences of the RW policy were quantified more comprehensively. Finally, the DID method was adopted for the empirical test, which excluded the interference of time and individual fixed effects to reasonably estimate the causal relationship between variables and to quantify more reliably the differences before and after the implementation of the RW policy.

2. Data, methods, and models

2.1. Model setting

The DID method is used mainly to evaluate the effect of policies concerning social administration [27,32]. This study adopted the DID method to evaluate the differences in water quality between resident and non-resident cities (i.e., the 58 cities included in the RW policy and 39 cities not included, respectively). The 58 cities implementing the RW policy were set as the “treatment group,” and those not involved in the initiative were set as the “control group.” To control for systematic differences between the two groups, 2019 was taken as the “event year.” The group effect represents the difference between the treatment and control groups, the time effect represents the inherent temporal trend before and after the treatment period, and the interaction terms of the policy and time variables represent the real effects of the policy.

The DID model can be expressed as follows (see Table 1 for details regarding the definition and processing of the variables):

$$TP_{it} = \beta_0 + \beta_1 Treat_{it} + \beta_2 Post_{it} + \beta_3 Treat_{it} \times Post_{it} + \beta_4 Controls_{it} + \varepsilon_{it} \quad (1)$$

where TP_{it} is the city's water quality i in year t, as determined from the total phosphorus concentration. Following China's rapid socioeconomic development, the phosphorus pollution load has become the primary pollutant in the Yangtze River Basin, and it is an important factor affecting the overall safety of the water ecological environment [33–39]. In equation (1), β_0 is the intercept, $Treat_{it}$ is a dummy variable with a value of 1 for cities that implemented the RW policy and a value of 0 for other cities, $Post_{it}$ is a dummy variable set to a value of 0 for 2016–2018 and a value of 1 for 2019–2021, β_1 is the difference in water quality improvement in the Yangtze River Basin between resident and non-resident cities before the implementation of the RW policy, β_2 is the difference in water quality improvement in the Yangtze River Basin of non-resident cities before and after the implementation of the RW policy, β_3 (the focus of this study) is the difference in water quality improvement in the Yangtze River Basin between resident and non-resident cities before and after the implementation of the RW policy, ε_{it} is the error, and *Controls* is a series of control variables, as explained in the following:

(1) Annual average population (*pop*). As the annual average population increases, the volume of domestic sewage generated also increases. (2) Total water resources (*water*). Water resources form an important material basis of the national economy. With the increase in the total water resources, the self-purification ability of urban water pollution becomes stronger. (3) Gross agricultural production (*agdp*). The gross agricultural industry might produce diffused pollution. Thus, with the increase in the output value of this primary industry, agriculturally diffused pollution also increases. (4) Gross industrial production (*indgdp*). With the increase in the output value of this secondary industry, the pollution produced by phosphorus-related enterprises also increases. (5) Length of sewerage pipes (*pipe*). The length of a sewerage pipe represents its sewage collection capacity. With the increasing length of the drainage pipes, the sewage collection capacity also increases. (6) Wastewater treatment (*wwt*). Wastewater treatment reflects the capacity for the treatment and disposal of sewage. With the increase in the length of the total sewage treatment, the capacity for

Table 1
Variable definition and processing.

Variable type	Variable symbol	Variable name	Variable description and processing
Dependent variable	*TP*	Total phosphorus	The concentration of total phosphorus
Main explanatory variable	*Treat*	Dummy variable of the implementation of RW policy	Variable in cities that implemented RW policy was set to 1; others were set to 0.
	Post	Dummy variable of time	The value is 1 for 2019 and later, and 0 for before 2019.
	pop	Annual average population	Natural logarithm
	water	Total water resources	Natural logarithm
	agdp	Gross agricultural production	Natural logarithm
	indgdp	Gross industrial production	Natural logarithm
	pipe	Length of sewerage pipes	Natural logarithm
	wwt	Wastewater treatment	Natural logarithm
	wwtr	Treatment rate of wastewater treatment plant	-

sewage treatment and disposal also increases. (7) Treatment rate of wastewater treatment plant (*wwtr*). This reflects the degree to which the centralized sewage collection and treatment facilities within a city are matched, and it is a landmark indicator for evaluating the sewage treatment work of a city. As the rate of treatment by centralized sewage treatment plants increases, the volume of sewage treated centrally increases, and the harm it poses to the aquatic environment decreases.

2.2. Samples and data

The data were collected from the China City Statistical Yearbook, the Yangtze River Center of the Chinese Research Academy of Environmental Sciences, and the Wind database. Of all the cities in the Yangtze River Basin, 102 have complete data available for model construction. Among them, water quality data were obtained from 1326 cross-sectional water quality monitoring stations located in major cities and at key nodes of the Yangtze River Basin. Dissolved oxygen, chemical oxygen demand, ammonia nitrogen, total phosphorus, total nitrogen, and other indicators were extracted primarily from water quality monitoring station data. For quality-control purposes, we matched the data obtained from the different sources, interpolated missing data, and removed samples with severe gaps. Additionally, to ensure the comparability of the samples before and after the implementation of the RW policy, the samples were cleaned according to the data completeness of the cities before and after the implementation of the RW policy. Simultaneously, to prevent the influence by outliers on model estimation, we truncated all continuous variables at both ends at the first percentile.

2.3. Descriptive statistics

Table 2 presents the descriptive statistics of the main variables. The average value of total phosphorus in the Yangtze River Basin was 0.083 mg L^{-1}, which falls within the Class II water standard for total phosphorus. The mean value of *Treat* was approximately 0.574 (i.e., 57.4% of the cities included in the sample implemented the RW policy).

Table 2
Descriptive statistics of the main variables.

Variables	Standard deviation	Mean	Minimum	Maximum
TP	0.048	0.083	0.011	0.419
Treat	0.495	0.574	0.000	1.000
lnpop	0.636	6.048	4.304	8.136
lnwater	0.919	13.462	10.970	17.165
lnagdp	0.957	14.250	9.896	16.771
lnindgdp	1.049	15.933	12.426	18.556
lnpipe	1.144	7.120	3.761	10.111
lnwwt	1.123	9.005	5.620	12.328
wwtr	0.086	0.918	0.398	1.219

3. Empirical analysis

3.1. Parallel trend test

The major difficulty in policy evaluation is that objects are not randomly selected. In this study, the selection of resident cities might have been affected by their willingness to participate and their water quality conditions. For example, cities with poor water quality were more willing to accept the RW policy. Thus, there might be inconsistencies in the trends of water quality improvement between resident and non-resident cities. For this reason, we tested the parallel trend assumption. Fig. 1 shows that the promotion effect of the RW policy on water quality in the Yangtze River Basin was statistically more significant in 2020, i.e., one year after implementation of the RW policy. However, the estimated coefficients before policy implementation were not statistically significantly different from zero, indicating no statistically significant difference in water quality between the treatment and control groups. Therefore, the DID model passed the parallel trend test and was found suitable for evaluating the treatment effect of the RW policy.

3.2. Baseline regression

Table 3 lists the baseline regression results for the impact of the

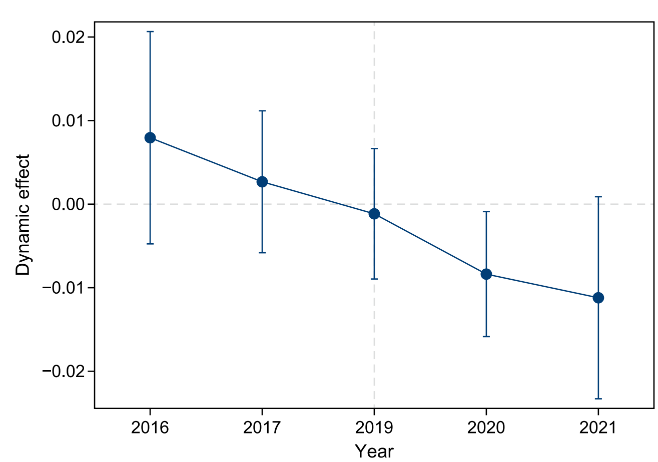

Fig. 1. Parallel trend test. The vertical dashed line shows the “event year” of 2019, and the horizontal dashed line shows the zero-value axis.

Table 3
Baseline regression results.

Variables	Model (1)	Model (2)
Treat×*Post*	−0.0126***	−0.0098***
	(0.0038)	(0.0034)
lnpop	-	0.0359**
		(0.0170)
lnwater	-	−0.0031*
		(0.0019)
lnagdp	-	0.0004
		(0.0022)
lnindgdp	-	0.0052***
		(0.0017)
lnpipe	-	−0.0117**
		(0.0049)
lnwwt	-	−0.0166*
		(0.0092)
wwtr	-	−0.0548**
		(0.0215)
Constant	0.0867***	0.1050
	(0.0015)	(0.1330)
Individual effects	Yes	Yes
Time effects	Yes	Yes
N	548	532
R^2	0.807	0.852

Note: Robust standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

RW policy on water quality in the Yangtze River Basin. In Model (1), the estimated coefficients $Treat \times Post$ were negative at the 1% significance level. After introducing the control variables, the sign and the statistical significance of the estimated coefficients did not change, as shown in Model (2), thereby indicating that the RW policy, in terms of scientific and technological assistance, substantially improved water quality in the Yangtze River Basin.

The coefficients of the control variables listed in Table 3 have important economic implications. The coefficients of the annual average population were positive, indicating that a large average annual population could worsen the water quality in the basin. The total amount of water resources had a more notable impact on reducing the total phosphorus concentration. Increasing the secondary industry output value can substantially increase the total phosphorus concentration. However, the output value of the primary industry had no statistically significant impact on the total phosphorus concentration in the Yangtze River. Previous studies found that approximately 60% of the total phosphorus pollution in the Yangtze River Basin originates from diffuse pollution, indicating that this pollution is generated from farmland or fugitive emissions in industrial production processes [37,38]. In the management of the total phosphorus pollution in the Yangtze River Basin, empirical results show that it is necessary to focus on the “three phosphorus” pollution sources (i.e., phosphate ore, phosphorus chemical enterprises, and phosphogypsum warehouses), other industrial enterprises, and non-agricultural diffuse pollution. Drainage pipe length and the total amount of sewage treatment have statistically significant impacts on improving water quality in the Yangtze River Basin. Additionally, increasing the rate of treatment by centralized sewage treatment plants helps reduce the total phosphorus concentration within the basin.

3.3. Placebo test

Referring to previous practices [40], we performed a placebo test by randomly selecting resident cities, generating a policy time for testing, and repeating the regression 500 times. The coefficient of the treatment group was distributed around zero (Fig. 2), indicating that the RW policy in the virtual sample had no statistically significant impact on water pollution, thereby passing the placebo

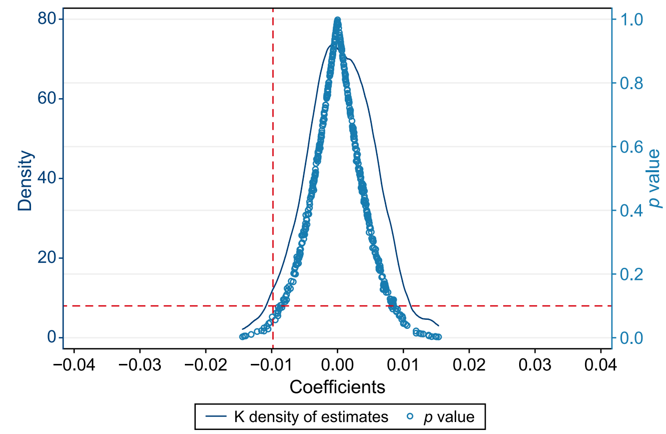

Fig. 2. Placebo test. The vertical dashed line shows the true estimate of the difference-in-differences model, and the horizontal dashed line shows the 0.1 significance level.

test. These results further illustrate that water quality improvement resulted from implementing the RW policy rather than from other unobservable variables or random factors.

3.4. Robustness test

3.4.1. Adjusting the window period

The selection of the window period affects the model estimation results. A short window period might lead to insufficient sample size and produce biased estimation results, whereas a long window period might alter the sample compositions of the treatment and control groups. We removed the 2016 data in this study and retained the 2017–2021 data. The results showed that all regression coefficients remained statistically significantly negative and had no substantial differences from the baseline regression results (Table 4).

3.4.2. Changing the proxy variable

We substituted the average value of the total phosphorus concentration with its maximum value (Table 5), which reflected the

Table 4
Regression results of the adjustment window period.

Variables	Model (1)	Model (2)
Treat×*Post*	−0.0084**	−0.0074**
	(0.0034)	(0.0034)
lnpop	-	0.0190
		(0.0148)
lnwater	-	−0.0025
		(0.0017)
lnagdp	-	0.0016
		(0.0023)
lnindgdp	-	0.0044***
		(0.0015)
lnpipe	-	−0.0096**
		(0.0046)
lnwwt	-	−0.0204**
		(0.0093)
wwtr	-	−0.0471**
		(0.0183)
Constant	0.0818***	0.2020
	(0.0015)	(0.1270)
Individual effects	Yes	Yes
Time effects	Yes	Yes
N	456	442
R^2	0.849	0.868

Note: Robust standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

Table 5
Regression results of changing proxy variables.

Variables	Model (1)	Model (2)
Treat×*Post*	−0.1010*	−0.0929*
	(0.0526)	(0.0536)
lnpop	-	0.1460
		(0.1540)
lnwater	-	0.0312
		(0.0232)
lnagdp	-	−0.0360
		(0.0297)
lnindgdp	-	0.0265
		(0.0232)
lnpipe	-	−0.0646**
		(0.0282)
lnwwt	-	−0.0154
		(0.1110)
wwtr	-	−0.3770**
		(0.1680)
Constant	0.3400***	0.0625
	(0.0227)	(1.6690)
Individual effects	Yes	Yes
Time effects	Yes	Yes
N	548	532
R^2	0.481	0.520

Note: Robust standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

most serious total phosphorus pollution in the water. When the maximum value was used as the explained variable, the regression coefficient $Treat \times Post$ was significantly negative at the 10% level, consistent with the above conclusions.

3.5. Dynamic test

We used a more rigorous econometric model to dynamically examine the effect of the RW policy on water quality (Table 6). The econometric model can be expressed as follows:

Table 6
Regression results of the dynamic test.

Variables	Model (1)
Treat×*ty*19	−0.0053
	(0.0039)
Treat×*ty*20	−0.0094**
	(0.0044)
Treat×*ty*21	−0.0147***
	(0.0055)
lnpop	0.0354**
	(0.0170)
lnwater	−0.0029
	(0.0019)
lnagdp	0.0002
	(0.0022)
lnindgdp	0.0051***
	(0.0018)
lnpipe	−0.0121**
	(0.0049)
lnwwt	−0.0165*
	(0.0091)
wwtr	−0.0534**
	(0.0215)
Constant	0.1080
	(0.1320)
Individual effects	Yes
Time effects	Yes
N	532
R^2	0.853

Note: Robust standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

$$TP_{it} = \delta_0 + \delta_1 Treat_{it} \times ty19 + \delta_2 Treat_{it} \times ty20 + \delta_3 Treat_{it} \times ty21 + \phi Controls_{it} + \varepsilon_{it} \tag{2}$$

where $ty19$, $ty20$, and $ty21$ indicate dummy variables for the RW in 2019, 2020, and 2021, respectively. δ_0 is the intercept, $\delta_1, \delta_2, \delta_3$ represent the size of the treatment effect in 2019, 2020, and 2021, respectively. ϕ is the coefficient of a control variable, and *Controls* is a series of control variables as described in Section 2.1. ε_{it} is the error.

As shown in Table 6, the coefficient of the impact of the RW policy on water quality in the Yangtze River Basin was −0.0053 in 2019, which was not statistically significant. The coefficient was −0.0094 in 2020 and −0.0147 in 2021, significant at the 5% and 1% levels, respectively; the coefficient peaked in 2021. This indicates enhanced improvement in water quality with time.

4. Heterogeneity analysis

Empirical results showed that the RW policy substantially improved water quality in the Yangtze River Basin. However, the improvement effect might vary because cities were at different levels of economic development and had different evaluation scores for implementing the RW policy. Therefore, we divided the sample into different groups based on economic development and evaluation score of the RW policy and explored the heterogeneity of the effect of the RW policy on water quality.

4.1. Heterogeneity analysis based on the level of economic development

Based on the median gross domestic product in 2016, this study categorized the studied cities into two groups: those with high economic development and those with low economic development. Generally, cities in the former group have two main advantages. First, the government and the residents have a stronger awareness regarding environmental protection and set higher requirements and standards for the ecological environment. Second, the government has more ambitious policy and fiscal preferences

Table 7
Heterogeneity analysis based on the level of economic development of cities.

Variables	Model (1)	Model (2)	Model (3)	Model (4)
Treat×*Post*	−0.0138**	−0.0110**	−0.0123**	−0.0093**
	(0.0056)	(0.0053)	(0.0049)	(0.0047)
lnpop	-	0.2500**	-	0.0049
		(0.1050)		(0.0121)
lnwater	-	−0.0053**	-	0.0010
		(0.0026)		(0.0024)
lnagdp	-	0.0026	-	−0.0029
		(0.0039)		(0.0026)
lnindgdp	-	0.0053	-	0.0039*
		(0.0035)		(0.0022)
lnpipe	-	−0.0083	-	−0.0163**
		(0.0062)		(0.0069)
lnwwt	-	−0.0146	-	−0.0133
		(0.0110)		(0.0140)
wwtr	-	−0.0474*	-	−0.0972**
		(0.0244)		(0.0392)
Constant	0.0810***	−1.1700**	0.0915***	0.3650*
	(0.0017)	(0.5810)	(0.0023)	(0.1880)
Individual effects	Yes	Yes	Yes	Yes
Time effects	Yes	Yes	Yes	Yes
N	275	273	273	259
R^2	0.837	0.862	0.815	0.853

Note: Robust standard errors in parentheses: ***p < 0.01, **p < 0.05, *p < 0.1.

for ecological environment protection, which cities with low levels of economic development might be unable to afford. However, as revealed by the heterogeneity test results (Table 7), the water quality improvement effect of the RW policy is more effective in areas with a low level of economic development. Some possible reasons for this are as follows. (1) The resident teams compensated for the shortcomings in terms of environmental governance technology and governance efficiency in cities with low economic development. (2) The resident teams built a better policy communication channel for cities with a low level of economic development, thereby improving the governance mechanism. (3) The resident teams broadened the source of environmental governance funds, attracting social organizations, enterprises, and other bodies to participate in water environment governance, thereby increasing the financial support available for environmental governance of cities with low economic development.

4.2. Heterogeneity analysis based on the evaluation score of the RW policy

Resident teams use science and technology to identify and address problems, which is reflected in the evaluation score of the RW policy. We obtained a comprehensive score based on local satisfaction and an expert group evaluation of the implementation of the RW policy. Then, we categorized the cities into two groups. Cities with a score higher than the median were assigned to the “excellent” group, and the others were assigned to the “general” group. As listed in Table 8, the regression coefficient of the RW policy was statistically insignificant for the general group. However, for the excellent group, the regression coefficient was significantly negative at the 1% significance level, indicating that high-score resident teams can effectively improve water quality in the Yangtze River Basin.

5. Conclusions and policy recommendations

The RW policy is an important approach to improving water quality. This study used the DID model to discuss the effect of the RW policy on water quality improvement in the Yangtze River Basin based on city-level data.

Table 8
Heterogeneity analysis based on evaluation score of the RW policy.

Variables	Model (1)	Model (2)
Treat×Post	−0.0036	−0.0136***
	(0.0036)	(0.0043)
lnpop	0.0406**	0.0478
	(0.0196)	(0.0301)
lnwater	−0.0008	−0.0039*
	(0.0020)	(0.0022)
lnagdp	0.0002	−0.0004
	(0.0026)	(0.0027)
lnindgdp	0.0017	0.0060***
	(0.0020)	(0.0019)
lnpipe	0.0018	−0.0123**
	(0.0037)	(0.0055)
lnwwt	−0.0219**	−0.0156
	(0.0091)	(0.0106)
wwtr	−0.0612***	−0.0580**
	(0.0218)	(0.0270)
Constant	0.0471	0.0367
	(0.1410)	(0.2050)
Individual effects	Yes	Yes
Time effects	Yes	Yes
N	378	390
R^2	0.822	0.856

Note: Robust standard errors in parentheses: ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

The main research conclusions are as follows. (1) Implementation of the RW policy substantially improved water quality in the Yangtze River Basin. (2) The water quality improvement effect of the RW policy showed statistically significant heterogeneity owing to differences in the level of economic development and the comprehensive score of the RW policy. Implementing the RW policy played a more important role in cities with low economic development. Moreover, a comprehensive excellent score of the RW policy indicates substantial improvement in water quality, whereas a general score of the RW policy indicates the need to strengthen the effectiveness of water quality improvements. (3) Strengthening infrastructure construction and increasing drainage pipe length, sewage treatment volume, and rate of treatment of centralized sewage treatment plants could improve sewage collection and treatment capacity.

Since the policy's launch in 2018, resident teams have provided strong scientific and technological support for urban water quality improvement in the Yangtze River Basin, motivated urban water quality improvement, and enhanced the capability to improve urban water quality.

Based on our research results, we propose the following recommendations.

(1) Cities in the Yangtze River Basin should actively seize opportunities for environmental improvement by implementing the RW policy. Cities undertaking the RW policy should actively use the scientific, technological, and policy advantages resident teams bring. Additionally, in-depth integration with the resident teams should be promoted. Thus, cities could share scientific research resources, technology, and data and overcome regional, organizational, disciplinary, and information barriers. Cities that do not introduce the RW policy, especially those with a low level of economic development, should actively seek to implement the RW policy, leveraging the strength of national environmental research teams.

(2) Total phosphorus is an important indicator of water quality in the Yangtze River Basin. Increased efforts must be made to manage industrial enterprises, such as the “three phosphorus” pollution sources and non-agricultural diffuse pollution. Simultaneously, strengthening the infrastructure construction of cities in the Yangtze River Basin, increasing the length of drainage pipes, and increasing the sewage treatment volume and rate of treatment by centralized sewage treatment plants are vital.

(3) Further optimization of the working mechanism of the RW policy is required, together with increased promotion and demonstration. The proposed RW policy is a new policy led by government departments, assisted by scientific and technological teams, and targeted at local cities with a resolute administrative will and a strong driving force. However, more cities could be involved and a regular resident working mechanism could be established. Local government and industry could participate more fully in local decision-making and industry emission reduction.

(4) Establishing social multi-participation mechanisms and increasing social funding support are required. Watershed ecological environment protection is a typical task of cross-regional ecological environment governance that requires the participation of all parties in society. Taking advantage of their resource endowments, cities should strengthen cooperation and prioritize coordinated regional development. It is necessary to use the incentivizing and guiding role of market prices to introduce social forces and capital. Additionally, the marketization process of ecological environment protection

should be promoted, funding channels should be broadened, and funding support for the RW policy should be increased.

CRediT authorship contribution statement

Jianglong Cui: Writing - Review & Editing, Writing - Original Draft. **Tiansen Zou:** Conceptualization. **Hengyuan Zhao:** Software, Data curation. **Xiaodie Zhang:** Investigation. **Guowen Li:** Resources. **Shengwang Gao:** Supervision. **Chunjian Lv:** Visualization. **Qiuheng Zhu:** Visualization, Supervision. **Lieyu Zhang:** Methodology, Conceptualization. **Haisheng Li:** Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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